# STUDIES ON GROUNDWATER DEVELOPMENT IN KANAVI HALLA SUB-BASIN OF GHATAPRABHA RIVER BASIN, BELAGAVI DISTRICT, KARNATAKA STATE, INDIA

**Thesis**

Submitted in partial fulfillment of the requirements for the degree of

**DOCTOR OF PHILOSOPHY**

by

**VENKANAGOUDA B B PATIL**

**(165020 CV16P05)**

**DEPARTMENT OF CIVIL ENGINEERING**

**NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA,**

**SURATHKAL, MANGALORE-575025**

**OCTOBER 2024**

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Under the guidance of

**Prof. K. N. Lokesh and Dr. Vinoth S**


**DEPARTMENT OF CIVIL ENGINEERING**

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# DECLARATION

I hereby declare that the Research proposal entitled **"Studies On Groundwater Development in Kanavi Halla Sub-Basin of Ghataprabha River Basin, Belagavi District, Karnataka State, India"** which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in Civil Engineering is a bonafide report of the research work carried out by me. The material contained in this Synopsis have not been submitted to any University or Institution for the award of any degree.

Place: NITK, SURATHKAL
Date: 04th October 2024

**VENKANAGOUDA B B PATIL**
165020 CV16P05
Department of Civil Engineering

# CERTIFICATE

This is to certify that the Research proposal entitled **"Studies on Groundwater Development in Kanavi Halla Sub-Basin of Ghataprabha River Basin, Belagavi District, Karnataka State, India"** submitted by **VENKANAGOUDA B B PATIL (Resister Number: 165020 CV16P05)** as the record of research work carried out by him, *is accepted as* ***Thesis*** submission in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy**.

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# Dedicated

**To My loving Grandfather Late. Avvappa B Patil**

To my loving and caring Guardians (Aunt and Uncle)

Dr B V Nadagouda and Shailaja B Nadagouda for

their Unconditional support and inspiration!

**To my loving parents**

**Late. Nirmala B Patil**

**And**

**Bhimanagouda A Patil**

**To my loving Soulmate Khushi V B Patil**

**And**

**My Adored and Cute Toddler "Trisha V B Patil"**

*Iam always Grateful to my supportive family members.*

***-Venkatesh***

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**-Venkanagouda B B Patil**

## ABSTRACT

Groundwater resources are extremely significant in the areas of arid and semi-arid tropics particularly in the hard rock terrains. This has led in serious search for groundwater resources. To meet the human requirements there is a need of artificial groundwater recharge, to enhance the quantity as well as quality. Hence, issues of water quality, water potentiality in the subsurface and its management need more attention in the present days. The quality of groundwater is determined for various parameters of groundwater Samples of Kanavi Halla Sub Basin (KHSB). The PCA technique is applied on water quality parameters, from which four and three components are extracted with 80.28 % and 75.01 % of total variance in pre monsoon and post monsoon season respectively. The extracted components suggest that the sources behind the higher loadings of each factor are by geological, agricultural, rainfall, domestic wastewater, and industrial activities. Based on water quality index (WQI), it was noticeably depicted that 2/3rd of the KHSB groundwater quality falls under poor to very poor condition and hardly 26% of groundwater available is portable. Hydrogeochemical study in KHSB for both drinking and agricultural suitability reveals as most of the sample are exceeding the limits as according to the recommended various standards. A total of 40 Vertical Electrical Sounding (VES) were conducted throughout KHSB. Totally 17 type of curves are obtained and 16 VES have been considered as good potential sites. Results shows that the maximum number of curves are associated with A type which refers to hard rock terrain, whereas curve associated with H type indicates water potential site. Dar-Zarrouk (D-Z) parameters are calculated in order to characterize the aquifer in order to check risk assessment for contaminants through seepage in terms of protective capacity. Total of 11 thematic layers are utilized for integration of Site suitability for groundwater recharge (GWRZ) mapping. They have classified as Very Low to High where the category with “Very low to low” covers larger area. Though several artificial recharge structures are existing, some more check dams, farm ponds, percolation tanks are recommended in this study area.



**Keywords:** GIS, RS, VES, Groundwater potential zones, groundwater recharge structures, LISS IV, Kanavi Halla, Water quality analysis, Multivariate statistics, correlation matrix, PCA.

**TABLE OF CONTENTS**

## LIST OF FIGURES

## LIST OF TABLES

**LIST OF ABBREVIATIONS**

| | |
|---|---|
| 1-D | : One-Dimensional |
| 2-D | : Two-Dimensional |
| 3-D | : Three-Dimensional |
| APHA | : American Public Health Association |
| AR | : Artificial Recharge |
| AWWA | : American Water Works Association |
| BIF | : Banded Iron Formation |
| BIS | : Bureau of Indian Standards |
| BW | : Bore well |
| CA | : Cluster Analysis |
| CGWB | : Central Ground Water Board |
| CPCB | : Central Pollution Control Board |
| DBR | : Depth to Bedrock |
| DEM | : Digital Elevation Model |
| DMG | : Department of Mines and Geology |
| DSS | : Decision Support System |
| DN | : Digital Number |
| D-Z | : Dar-Zarrouk |
| E | : East |
| EC | : Electrical Conductivity |
| ER | : Electrical Resistivity |
| FA | : Factor Analysis |
| GIS | : Geographical Information system |
| GNSS | : Global Navigation Satellite Systems |
| GSI | : Geological Survey of India |
| GW | : Groundwater |
| GWPZ | : Ground Water Potential Zones |
| GWQIs | : Groundwater Quality Indices |
| GWR | : Ground Water Recharge |
| GWRPZ | : Ground Water Recharge Potential Zones |

| | |
|---|---|
| HP | : Hand Pumps |
| IGIS | : Integrated Geo Instruments & Services private limited |
| IRS | : Indian Remote Sensing Satellite |
| ISI | : Indian Standards Institution |
| IWRM | : Integrated Management of Water Resources |
| KHSB | : Kanavi Hall Sub Basin |
| KR | : Kelly's Ratio |
| LiDAR | : Light Detection And Ranging |
| LISS | : Linear Imaging Self-Scanning Scanner |
| LU/LC | : Land Use / Land Cover |
| LUP | : Land Use Planning |
| Ma | : Mega Annum/Million Years |
| MAR | : Managed Aquifer Recharge |
| MAR | : Magnesium Adsorption Ratio |
| MCDM | : Multi-Criteria Decision Making |
| MCE | : Multi-Criteria Evaluation |
| MH | : Magnesium Hazard |
| MIF | : Multi-Influencing Factor |
| N | : North |
| NASA | : National Aeronautics and Space Administration |
| NBSS | : National Bureau of soil Survey |
| Nd | : Neodymium |
| NIR | : Near-Infrared |
| NRSC | : National Remote Sensing Centre |
| PAN | : Panchromatic |
| PBC | : Precambrian Basement Complex |
| PC | : Principal Component |
| PCA | : Principal Component Analysis |
| pH | : Hydrogen Ion Concentration |
| POM | : Post Monsoon |
| PRM | : Pre Monsoon |

PI : Permeability Index

RS : Remote Sensing

RSC : Residual Sodium Carbonate

S : South

SAR : Sodium Adsorption Ratio

SI : Saturation Index

SPSS : Statistical Package for the Social Sciences

SRTM : Shuttle Radar Topography Mission

SSP : Soluble Sodium Percentage

SWIR : Short Wave Infrared

TDS : Total Dissolved Solids

TH : Total Hardness

TIR : Thermal-Infrared

U-Pb : Uranium-Lead

USA : United States of America

USSL : United States Salinity Laboratory

VES : Vertical Electrical Sounding

W : West

WHO : World Health Organization

WOA : Weighted Overlay Analysis

WQI : Water Quality Index

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

Groundwater is key resource for any activities on the planet earth for all organisms. It is also known as hidden resource since it is beneath the surface. Groundwater occurs in various conditions and its occurrence and availability differs from place to place. Since this most important resource is depleting both in quality and quantity it has made us to think on each drop of water. Growing industries, agricultural activities, urbanization, vagaries of rainfall and many more anthropogenic activities have impacted extremely on groundwater resources and thus resulting in depletion of groundwater all over the world. Groundwater may be available at shallower depth in some places, may be influenced by the heavy precipitation and lithology of that area. Groundwater is essential for all, since non accessibility of the surface water in some places where it is required. Groundwater refers to the water found beneath the Earth's surface, residing within underground streams, aquifers, and filling the gaps between sedimentary rock particles. It occupies crevices and cracks across different types of rocks, and permeates through the pore spaces within sedimentary formations. Most of the study says that groundwater is usually free from color, odor and has very little dissolved solids. It is also not usually affected by natural factors such as drought. The basis of all life is water, a crucial natural resource. As the cornerstone of ecological survival, it is a fundamental need for humans (Rahaman, M. M., & Varis, O. 2005). A chemical molecule known as water can be found in the states of liquid, solid, and gas. Water is the ideal tool for living activities because of its diverse physical and chemical properties (Schwarzenbach et al. 2016). Water is a fundamental comfort and a necessity for both humans and other living things. There wouldn't have been any life without water. Water is also essential for other aspects of social and economic development, such as irrigation, energy production, home and industrial use, and environmental preservation (Panayotou, 1993). The hydrologic cycle naturally includes groundwater, making it a significant national resource (Oki, T., & Kanae, S.,2006). Therefore, examining water resources requires scientific research and efficient administration. Groundwater (GW) is becoming increasingly scarce due to rising agricultural and industrial activity and ongoing monsoon whims, and it can no longer provide even the minimum amount of water needed for drinking. Thus, the quality and quantity of surface and groundwater are of the utmost significance. It is obvious that there are water and environmental problems at the moment. In densely populated countries groundwater is the essential source for both domestic and agricultural activities since there is lack of availability of surface water (Biswajit Das and Sunil Kumar Singh, 2016). Water scarcity has become a major problem especially in semi-arid regions due to insufficient rainfall throughout the globe. This has led to serious search for groundwater resources. Groundwater resources are extremely significant in the areas of arid and semi-arid tropics particularly in the hard rock terrains.

In today's scenario, developing countries like India are the maximum users of groundwater which has resulted in the extraction as twice as total quantity of groundwater consumed in USA (Shah, T 2005). Concern for managing such essential renewable resource has been increasing from past few decades. This is due to the sudden increase in population and their associated activities such as agricultural, urbanization, industries etc. Every biotic and abiotic component on the planet earth is much depended on water resource directly or indirectly. Only four in ten people on the planet have access to clean water. If the current scenario continues, future worries of a water-related war could grow more intense. India's water resources are unevenly distributed both physically and temporally. Innovations in science and technology have gained popularity recently to meet the water demands of humanity and many other living things. These developments make it possible for us to access the water resources that the earth has to offer in order to meet the needs of humans and many other living things. Therefore, effective scientific methods for locating suitable aquifer zones for exploitation and recharging are absolutely crucial. Due to the country's unique physiographic circumstances and the monsoon's characteristic behaviour, there is an uneven distribution of water throughout India. The urban lifestyle, population growth, and improper agriculture practices have all gotten worse recently. Even now, there is an acute water shortage throughout most of the nation. To improve society and the country, groundwater resources should be adequately planned for, used, handled, and managed. Since surface water supplies (rivers, lakes, and man-made basins) are less accessible than needed, India has seen excessive groundwater exploitation in the previous two to three decades, particularly for agricultural and industrial needs. For the survival of all life, including that of human beings, the soil, water and vegetation are the most crucial natural resources. Sustainability of groundwater, in terms of quality, is a growing concern, particularly around urban and industrialized centres. For any country, agriculture is one of the major source of food production. Groundwater among the other water resources is a major concern on planet earth, as it is the purest form of water compared to the other kind of water sources. Also, contamination of ground water causes risk for human beings and other animals too. Developmental activities, such as growing population, industries, agricultural activities, city expanding, urbanization and many more causes, directly threaten the water sources, both on surface as well as ground water. It cannot be said that the water is available in its purest state either on the surface or in the subsurface, but compared to the present scenario, groundwater is much better than the surface water in terms of purity. Effective organization and planning of groundwater is of extreme importance (Kumar, et.al., 2008).

Prospecting of groundwater in hard rock terrains, arid and semi-arid regions are extremely important for successful exploration and to reduce the number of failures. Many researchers are following different methods in exploring this very essential life sustaining resource. There are various techniques to search the groundwater since long. Surface investigations are cost effective and also success rate is also high. Geophysical surveys have been most extensively used because of the basic benefit of providing more accurate results than other methods. Among various geophysical methods electrical resistivity method is extensively used for groundwater investigation. During the early 1900s, electrical methods, particularly the resistivity method, were initially developed. However, their widespread use began in the 1970s, primarily due to the increasing availability of computers for data processing and analysis. The utilization of Electrical Resistivity methods has become extensive in various fields, including the quest for viable groundwater sources, monitoring different types of groundwater pollution, conducting engineering surveys to pinpoint sub-surface voids, faults, fissures, and permafrost, among others. In archaeology, these methods aid in mapping out the extent of buried remnants of ancient structures, along with numerous other applications. This method of subsurface investigation through electrical resistivity helps ascertain the composition of overlying material, identifies the depth to bedrock, measures the thickness of sand, gravel beds, metal deposits, and aquifer zones. Moreover, it facilitates the location of steeply inclined contacts between various Earth materials. Geophysical methods have found extensive use in groundwater prospecting due to the strong correlation observed between electrical properties, geological formations, and fluid content. In the past decade, resistivity sounding and profiling have proved to be valuable tools in prospecting for groundwater resource in many countries. Among various electrical methods, the most popular method, best tested and most extensively used method is the Schlumberger vertical electrical sounding (VES) to determine aquifer geometry and groundwater quality. The present study intends to indicate the significance of electrical resistivity technique to demarcate the water/aquifer zones.

This method is frequently applied in both soft and hard rock terrains. In areas with hard and impermeable bedrock that is unsaturated, dense, and nonporous, high resistivity values typically display a noticeable difference compared to the intermediate resistivity values found in the saturated zone. Moreover, less permeable silts and relatively impermeable clays exhibit very low resistivity values, creating a distinct contrast in the data obtained. The vertical electrical sounding is one of the approach of electrical resistivity, can be interpreted to obtain sub-surface litho zones, prevailing hydro-geological conditions and aquifer parameters such as specific yield/storage coefficient, hydraulic conductivity, etc. Quantitative analysis of vertical electrical depth soundings involves either the indirect method where field curves are compared with theoretical master curves or the inverse method to determine layer resistivity and thicknesses.

Electrical resistivity method is one of the most practicing technique since long to the present time for investigating the availability of groundwater. The electrical resistivity instrument is actually "plug and play" since its assembly and use requires only the most basic familiarity of electronics. The Electrical Resistivity methods are commonly employed for conducting comprehensive surveys, both at a regional and detailed level, in groundwater investigations. This preference is due to their exceptional resolving capabilities, cost-effectiveness in comparison to drilling, and their extensive applicability in various field conditions. Consequently, in this current study, the focus is on utilizing the electrical resistivity method, specifically employing vertical electrical sounding (VES) with the Schlumberger configuration. The Schlumberger method of electrical resistivity for detecting a shallow/deep source of groundwater in fractured/fissured, hard rock zones is extensively used. Hence, the electrical resistivity, in particular, vertical electrical sounding (VES) with Schlumberger arrangement method is the most popular one for groundwater prospecting and the most appropriate for groundwater prospecting. In addition, with electrical resistivity technique, Remote sensing and GIS approach may increase the accuracy of the investigation. Delineation of groundwater prospect zones can be identified easily with the help of this integrated approach and the success rate of the bore wells can be increased. Targeting the groundwater in hard rock terrains like Deccan basalt, gneissic, quarzitic is not always easy. Groundwater in crystalline rocks mainly occurs in shallow weathered zones in narrow limited extent. As fracture zones are mechanically weak and foci for weathering, they can store and transmit more groundwater than intact rocks and form the main aquifers (Magaia et al., 2018). It is essential to carry out the combined studies on the geological, geomorphological and hydrogeological for better assessment of groundwater in any given basin or area.

The term “quality” includes the physical, chemical and biological characteristics in nature. As long as we are unable to understand the chemical nature of water, the complete knowledge of water remains unknown. Since the quality of water is directly linked with human welfare, it is a vital concern for mankind. Most population in India is highly dependent on groundwater since it is one of the significant source of drinking water supply and irrigation (Mahmood and Kundu, 2005; Phansalkar et al., 2005). The groundwater is believed to be relatively cleaner and free from contamination than the surface water. Groundwater undergoes contamination from the surface level to the unconfined and confined aquifer levels. Groundwater starts acquiring the respective chemical characteristics, as it starts interacting with geological, climatological, topographical and pedalogical conditions, which lead to accretion of salts in it. Walton

(1970) has mentioned that the quality studies on the groundwater explains the concentration of different cations and anions, along with the idea of occurrence, discharge, movements, storage and geological history. Qualitative studies on water is also essential to understand the suitability for domestic, irrigational and industrial applications (Walton, 1970). The term "quality" encompasses the natural attributes of physical, chemical, and biological characteristics. Amongst the various water quality parameters; fluoride ion, nitrate, heavy metals show distinctive properties as its concentration in optimum dosage of drinking water is beneficial to health. If this concentration is beyond a specified limit, human health can get affected. Excess fluoride, nitrate and heavy metal concentration, both in the surface water and groundwater in many parts of the world, is a cause of greater health concern. Availability of natural water resources are very limited in the arid and semi-arid areas; rainfall and runoff have diverged, both spatially and temporally, across the region (Biswajit Das and Sunil Kumar Singh, 2016). For both domestic and agricultural activities, groundwater is the chief source due to lack of surface water in these regions.

Agriculture is the chief livelihood of the people of Kanavi Halla Sub Basin (KHSB) of Ghataprabha river covering parts of Gokak, Bailhongal and Saundatti taluks of Belagavi district of Karnataka State, India. The people in this area are dependent on seasonal rainfall and canal water along with groundwater for both drinking and agricultural works throughout the year. Due to the depletion of the water quality of both bore well fitted with hand pumps and bore wells fitted with submersible pumps in the study area especially in the non-rainy seasons, there is an urge to develop the groundwater quality. Various guidelines and policies have been adapted globally to control and prevent environmental degradation resulting in sustainable use of earth’s resources (Tiwari et al., 2015). Implementation of such policies would help in monitoring and preventing the overall depletion of the quality and quantity of these resources which is the need of the hour. Therefore, suitable methods for the management of existing water resources are much essential for the existence of human beings (Brabec et al., 2002).

Geospatial technologies refer to a group of tools used primarily for mapping and analysing spatially referenced statistical data from various fields (De Smith et al., 2007). These encompass geospatial technologies like electronic surveying, geographic information systems (GIS), remote sensing, photogrammetry, light detection and ranging (LiDAR), global navigation satellite systems (GNSS), and image processing. Geospatial technologies revolutionize the way data is gathered and analyzed to create maps essential for diverse applications. Maps stand as crucial end products for numerous emerging geospatial uses. One indirect method for assessing subsurface geological conditions, particularly identifying lineaments and weathered rock zones, is through electrical resistivity imaging (Mageshkumar et al., 2019). The capability of remote sensing data to create information in both the spatial and temporal domains is by far the biggest benefit of employing it for hydrological modelling. Techniques like Remote sensing and Geographical Information Systems are effective for making decisions quickly for sustainable water resource management (Darkwah et al., 2021).

The occurrence, origin, and movement of groundwater are significantly influenced by the geologic characteristics of aquifers, such as their lithology, thickness, structural makeup, and permeability. Aquifers are restricted to weathered or cracked zones. Therefore, in order to thoroughly evaluate groundwater conditions, significant hydrogeological research is frequently needed. Groundwater management and development require a sizable amount of multidisciplinary data from numerous sources. The underground phenomenon is known as the groundwater aquifers. As direct detection of features such as lithology, geology, geomorphology, drainage patterns, soil composition, land use/land cover (LU/LC), and hydrological characteristics remains challenging, reliance on indirect analysis becomes necessary. In recent times, multi-criteria decision making (MCDM) has emerged as a valuable tool for mapping and managing resources, particularly for natural resources like water. Geospatial techniques have gained widespread use in identifying and delineating groundwater resources (Chowdary et al., 2013; Okoli et al., 2017; Okoli et al., 2019). Studies hypothesize that the MCDM technique holds significant importance in quantifying and effectively managing water resources. Senanayake et al. (2016) highlight that the Multi-Influencing Factor (MIF) is a subjective technique, emphasizing that the weight and significance of thematic information greatly influence the accuracy of the final results. The "Weighted Overlay Analysis" (WOA), one of several additional appropriateness analysis techniques, enables us to mix, weigh, and rank several sorts of thematic information. GIS users can evaluate various alternatives based on several competing criteria and objectives by integrating Multi-Criteria Evaluation (MCE) methodologies. A significant role is played by the prospective application of a combined GIS-MCE strategy in the creation of spatial decision support systems (Carver, 1991). Groundwater potential zonation refers to the use of surface and subsurface suggestive factors by direct or indirect scientific approaches to analyse both quantitatively and qualitatively the potentiality of the groundwater zones in a given location. Remote sensing and field verification make it simple to retrieve the surface features or parameters. In contrast, direct observations in the potential exposures, electrical resistivity approaches, and observatory wells make it possible to measure sub-surface characteristics. Land use/Land cover and lineament mapping are performed using remotely sensed data. Additionally, the examination of the drainage basins and the geomorphological mapping support it. The goal of the current effort is to develop a connection between the electrical resistivity (ER) approach and RS and GIS-based methodologies for identifying and mapping potential groundwater zones. Recognising geological, structural, and geomorphological features being the foundation for determining rank/weightage is essential.

Due to the geographic spread, the building of small water-harvesting buildings has gained relevance recently (Kumar et al., 2008). In the present century special attention has been paid to artificial groundwater recharge in water resource management since there is scarcity of fresh water availability. Several ways were used in the past history to recharge groundwater without much technologies. Since there was no such scarcity of fresh water in the past history as what we are facing in the present century the people were not concentrating much on this topic. Identifying the potential region for ground water recharge becomes important for fulfilling the basic requirement of all human beings and all animals. Recharging methods are many and it depends on the need, possibilities and several factors which will influence the recharging. Geologically one has to study very systematically to locate groundwater recharging potential zones(GWRPZ). Therefore, it is important to plan storage and recharge structures ingeniously so that water may be used effectively during the summer.

Understanding runoff is necessary for accurate estimation and quantification of surface and groundwater. The aquifers' and the sub surface’s complexity could lead someone to suggest an incorrect recharge structure (Todd & Mays, 2005). For correct findings, a number of variables must be taken into account. As a result, multi-criteria analysis is useful in this context. Bandyopadhyay, et al.2016, reported research using geo-informatics to determine the prospective zones for groundwater in a hard rock environment. Integrating remote sensing data with a survey of India's topographical maps and field validation is very useful. To evaluate the hydro-geomorphological features of the research region, hydrogeological features (such as slope, drainage density, lineaments density, and other geological and geomorphological units) that affect groundwater occurrence were extracted and integrated. Later, a map of the groundwater potential was created by overlaying thematic layers with grid-wise theme and class weights. Krishan et al. 2016, worked with WQI to assess the drinking water quality of the groundwater. For the purpose of upcoming planning and management, WQI is primarily utilised to evaluate the spatial variance of groundwater quality status. The water quality parameter is defined by BIS: 10500-2012 and central pollution control board (CPCB) standards.

Since Belagavi district is considered under the category of excess fluoride zone in groundwater as per the CGWB report (CGWB 2007), groundwater of some parts of the Belagavi district was assessed to check the quality in detail. Water is a renewable resource but it also can act as a non-renewable based on the usage and consumption pattern. Hence, issues of water quality and its management need more attention in the present days. To understand the quality of the water in Belagavi, there is a need of quality assessment for various parameters, which can analyze and suggest further development. The concern towards groundwater is because of the various pollutants entering into the groundwater due to various activities and also the seawater intrusion in coastal areas.

## 1.2 STUDY AREA DESCRIPTION

The study area, which includes the Gokak, Bailhongal, and Saundatti taluks of the Belagavi district, is a sub-basin of the Ghataprabha river basin and has typical hard rock topography. The sub-basin, which has a surface area of 686 sq. km, is located between latitude $15^{0}$51' 53" and $16^{0}$ 12' 30" N and longitude $74^{0}$42' 18" and $75^{0}$02' 21" E. The research area is covered by toposheets of Survey of India with codes 47 L/12, 47 L/16, 48 I/13, 47 P/4, 48 I/9, and 48 M/1. Before joining the Ghataprabha River at Gokak, Kanavi Halla flows over a distance of 55 kilometres from its source in the village of Suthagatti. The research area receives 563mm of rain on an average. The Kanavi Halla sub-basin (KHSB) is located in the northern, dry portion of Karnataka State and is a part of the semi-arid belt (Figure 1.1).

### 1.2.1 Geology

The primary rock types in the region include gneisses, quartzites, and basalt. The region is made up of Deccan basalts that date from the Cretaceous to the Tertiary, Kaladgi group limestones and quartzites are from the Proterozoic and Archean gneisses. The detailed geology of the study area is discussed in chapter 3 under the title "Geology and Geomorphology."

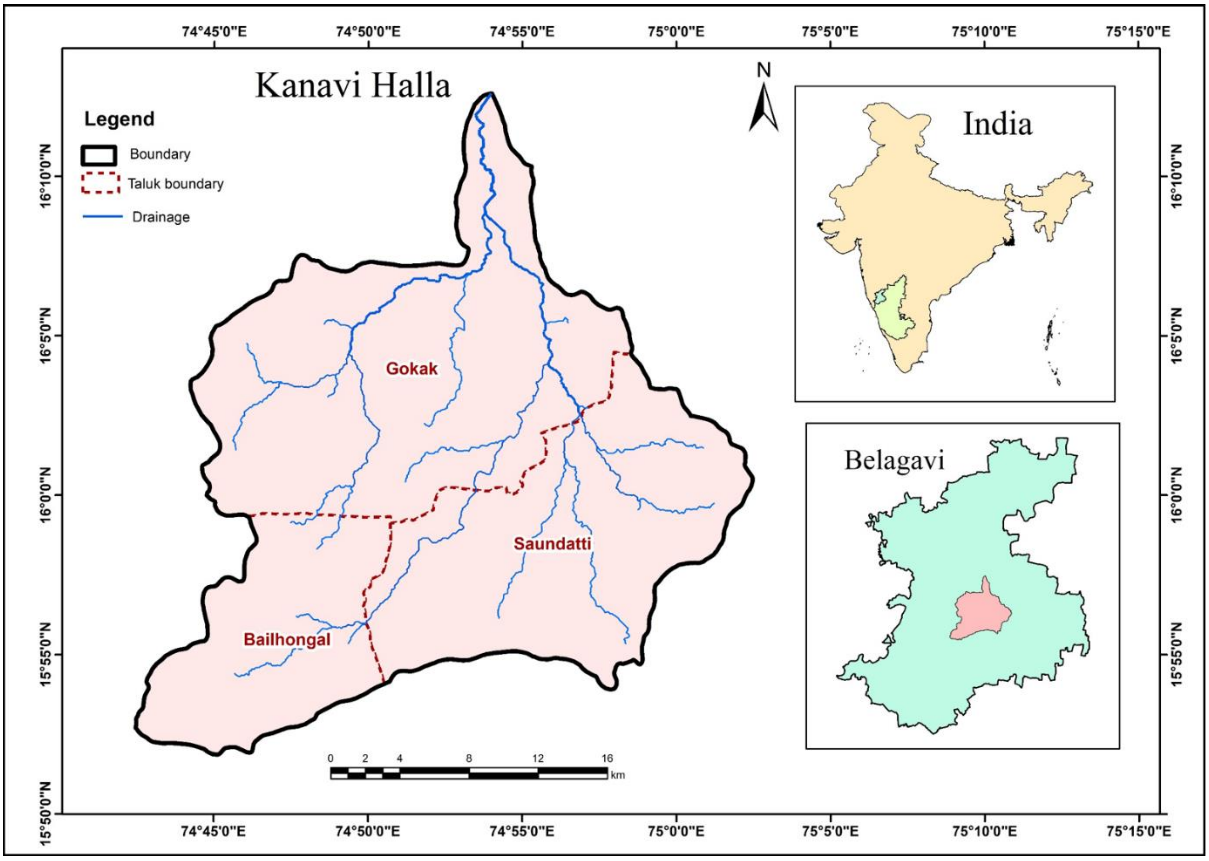



Figure 1.1 Location Map of the study area

### 1.2.2 Hydrogeology of the study area

Factors like geology, soil, relief, rainfall, temperature and other natural aspects govern the availability and movement of groundwater. It is essential to know the basics of geology, topography and soil of the study area to understand the movement of groundwater and its occurrence. Geology of the study area chiefly comprises of gneisses, quartzites and basalts along with some limestone and sandstone. The area comprises of Deccan basalts which are of tertiary to Mesozoic age, limestones, Sandstones & quartzite belongs to Kaladgi group of Upper Precambrian age. The gneisses belong to Peninsular Gneissic complex group of Archean age. The lithostratigraphy of the area is given in Table 1 (CGWB, 2007; CGWB, 2016-17; GSI, 2005; Ramakrishnan, Vaidyanadhan, 2010). The KHSB area is covered dominantly by Basalt and Limestone. In some part of the study area, it is observed through borewell logs, the contact zone in the deeper subsurface occurs in between Basalt and Gneiss, Quartzite and Gneiss may be groundwater potential zones.

Groundwater in study area is extracted for domestic purposes using hand pumps and for agricultural activities through bore wells. The direction of flow of groundwater is from recharge to discharge area and is the common trend which also depends on the topography. The groundwater in the present study area flows towards north direction and joins the Ghataprabha River near Gokak. The KHSB is dominantly occupied by sandstone varities and hard rock among which basaltic lava flows are the main lithology. Usually these kind of hard rocks are poor both in storing and transmitting water, except in few locations depending on the local conditions. Hence aquifers are inadequate in nature. Groundwater occurs in weathered formations under unconfined condition and in jointed and fractured formations under semi-confined condition. Permeability in Deccan basalts is low to medium and performs as a multilayer aquifer (CGWB, 2007 and 2016-17). Sometimes the Deccan basalts act as good repositories of groundwater when it consists of fractures, dissimilar flows and interstitial pore spaces of vesicular zone. Limestone with solution cavities are more potential zones when compared to weathered and fractured ones. Weathered zone in gneisses varies from 7 to 12 m and water bearing zones spread down to 80 m. Aquifers with depth of 0 to 20 m bgl depict as weathered and fractured formations. These formations exhibit groundwater under unconfined condition with 5 to 15 m as average thickness of the aquifer (CGWB, 2007).

### 1.2.3 Climate

The climate in Belgaum is tropical. The height of Belgaum moderates the tropical climate, which has a rainy season from June to October because of the monsoon and a dry season from November to March. It is very hot in April and May, just before the monsoon, and there are sporadic but possible showers. From November to March, it can get chilly at night, and in the rainy season, especially in July and August, daytime temperatures can get downright chilly, hovering around 25 °C (77 °F). KHSB forms a part of semi-arid belt and agro-climatically, it is a part of Belagavi district, a northern dry zone of Karnataka State. KHSB may be classified into three seasons. Winter season is from November to end of February, from mid of March to end of June is treated as summer. Monsoon starts from mid-June and continues till the end of September. January being the coldest month, May being the hottest month and winter season is of short duration in semi-arid and hard rock region. Generally, summers are severe in semi-arid regions, but the nights are cool. The average rainfall in the study area is 563mm.

### 1.2.4 Vegetation

The sort of vegetation that grows depends on the climate or vice versa. As there are good number of canals present along Ghataprabha River in the vicinity of study area, it receives ample water for agricultural purposes especially for sugarcane. Other part of the study area is dry land where the farmers grow maize, Jowar (Sorghum), groundnut and wheat and are primarily reliant on rain.

## 1.3 SCOPE OF THE STUDY

The nature and composition of the planet are diverse. Since the sub-surface is unknown, there is spatial variance in the sub-surface. Additionally, because of the earth's dynamic geological activity, subsurface formations may vary in nature. In hard rock terrains like the present study area, these geological formations serve as the primary groundwater channel. Therefore, gathering information about the subsurface via efficient and trustworthy approaches is necessary for scientific knowledge. Drilling is a direct way; however, it is too expensive to use. Therefore, there is a need for indirect approaches that are practical from an economic standpoint, such as geophysical methods, RS & GIS, modelling, and simulations. Despite the fact that water is a naturally occurring and replenishable resource, both groundwater quantity and quality are severely limited. Therefore, there is a need for studies on groundwater potentiality, groundwater recharge potentiality, and groundwater quality with reference to water management. We cannot anticipate the same groundwater quality at the same location year-round because the groundwater quality is dynamically changing over time. These days, GIS and mapping techniques are quite popular because, with the right data, maps can convey the most information graphically, spatially, chronologically, and with the help of legends.

The artificial recharge structures might be recommended for specific locations to enhance the quality and quantity of groundwater (GW). This study aims to provide first-hand knowledge to local authorities and planners about appropriate locations for groundwater exploitation, the types of wells and bore wells needed, the depth of wells needed, the quality of the groundwater, the suitability of the site for GW recharge structures, and the kinds of recharge structures to be built. Other river basins and catchments could benefit from this kind of study, particularly those with hard rock terrain.

With regard to water one has to know the two essential thoughts on it: (i) Management and (ii) Sustainability (Vasantrao et al., 2017). To reach sustainability, rethinking on basic needs is must as water is the most basic necessity. It is required to estimate how much of water is really needed. For any ecosystem/organism, water is important than any other substitute, therefore the challenge is to maintain sustainability of the most precious natural resource. To manage water resources, data regarding the availability of groundwater is significant. Geophysical exploration methods like electrical resistivity methods are practiced for investigating the productive groundwater especially in the rain fed areas. For better water resource management and sustainability, combination of electrical resistivity method, geo-electrical modeling and computation of D-Z parameters assessment play a vital role.

## 1.4 OBJECTIVES

This study aims to identify and map the groundwater potentiality, groundwater recharge potentiality, and water quality index of the Kanavi Halla sub-basin(KHSB) of Ghataprabha River basin, Belagavi District, Karnataka State, India, using multidisciplinary approaches like electrical resistivity technique, RS & GIS, and groundwater quality parameters. The following are the primary objectives;

1. To delineate ground water potential sites using integrated study of electrical resistivity method and remote sensing & GIS
2. To study hydro-chemical assessment and the suitability of groundwater for drinking and agriculture in the semi-arid areas.
3. To delineate the potential locations for groundwater recharge structures using integrated study of geo-electrical resistivity survey, remote sensing & GIS.

## 1.5 ORGANISATION OF THESIS

**Chapter 1** introduces importance of water resources generally, focusing on groundwater investigation. Additionally, location of the study area, geology, hydrogeology, climate, vegetation of the study area, scope and objectives of the study and the thesis outline are given.

**Chapter 2** involves an in-depth review of literature aimed at extracting research objectives while encompassing all facets of prior research. It commences with an examination of water resources and the diverse applications of multidisciplinary groundwater studies. This chapter establishes a correlation between the research objectives and previous endeavors by investigating groundwater quality, exploration, recharge studies, and addressing the existing gaps to devise potential solutions.

**Chapter 3** deals with the geology and geomorphology, which provides extensive details regarding the lithology of the surface and subsurface regions, the geological structures, and how these relate to groundwater exploration in the study area. This chapter starts with the regional geology and deals with the geology of the study area. For knowledge of groundwater exploration, geomorphology is a crucial factor. Regarding its connection to groundwater, the surface's shape and deformation provide a wealth of information. In order to comprehend the geomorphology of the study area better, soil type is also considered and discussed.

**Chapter 4** deals withgeophysical investigations conducted within the study area, focusing on introduction to various geophysical techniques. The discussion primarily centres on the resistivity method, highlighting its principles, instrumentation, and methodologies in detail. It investigates groundwater exploration. The electrical resistivity method, a geophysical technique, is employed in this chapter as a backup technique for gathering subsurface data. One of the most popular interpretation techniques are then utilised to understand the resistivity data. The resistivity data is used to determine the depth to bedrock (DBR) and weathered zone. The Dar-Zarrouk (D-Z) parameters are also determined using this method. Studies on geometry of the aquifer formed has been discussed by using geo-electrical modelling.

**Chapter 5** focuses on the geochemical analysis of water samples from KHSB. In this chapter, a comprehensive overview is provided regarding geochemistry, analytical methodologies, the spatial distribution of hydro chemical parameters, and the categorization of groundwater based on diverse criteria proposed by various researchers. It also focuses on the factors of groundwater quality, which is also a crucial component for the potential use of groundwater. A thorough investigation into the study area's drinking water quality is done in this chapter. In order to enhance the quality of the data used in water quality analysis, quality assurance procedures are also applied, such as validating the accuracy of the analysis (APHA et al., 2012). To comprehend how the various water quality metrics, interact with one another, correlation studies were carried out using multivariate statistical analysis. This chapter primarily delves into the examination of drinking water suitability through factor analysis and the water quality index method. Additionally, it explores agricultural suitability using traditional graphs and an analytical approach.

**Chapter 6** delineates the research conducted on groundwater recharge within the study area. It encompasses the methodology of multi-criteria analysis employed to identify potential zones for groundwater recharge. The investigation of the site suitability for the chosen artificial recharge structures is then completed. In order to achieve the most recharge possible, the best locations and recharging techniques can be used. The culmination of this chapter is the creation of a thematic map depicting Groundwater Recharge Potential Zones (GWRPZ).

The concluding section of the thesis is **Chapter 7** which encapsulates the primary discoveries of the research. Additionally, it offers recommendations for potential avenues of future study or areas for further exploration.

References are incorporated after key chapters in the thesis, providing essential information. A bibliography serves to compile all cited literature throughout the document. The referenced materials, including research papers, books, reports, online sources, and websites, are organized alphabetically. Authors' names are arranged alphabetically to facilitate easy navigation through the referenced content.

Following the references, an appendix section is included. Appendix A contains the graphs plotted for 40 VES using IPI2WIN. Appendix B contains plates show casing field photographs. Appendix C comprises publication details of the study. Appendix D contains a concise resume.

# CHAPTER-2

# REVIEW OF LITRATURE

## 2.1 GENERAL

The groundwater resource has many facets that determine by its location, occurrence throughout time, size, features, accessibility conditions, and the work required to mobilize it; as a result, all of these factors must take into consideration in the context of demand (Singh et al., 2011). Groundwater is a renewable but limited natural resource that is important for human survival and social and economic advancement and is an essential element of the environment. Compared to the near-surface elements of the terrestrial water cycle, groundwater responds to weather conditions more slowly (Changnon et al., 1988). In shallow aquifers, residence time (the quantity in storage to the average replenishment or discharge) can range from months to a million years or more (Sturchio et al., 2004). As a result, groundwater may take some time to return to its previous dynamic equilibrium condition. In arid and semi-arid areas where people depend on fresh groundwater for agriculture and domestic needs, withdrawals can quickly exceed net recharge (Postel, 1993). Even in affluent countries, the laws protecting groundwater rights have not altered in response to the growing demands on water resources brought on by population increase and economic development (Livingston and Garrido, 2004). Groundwater depletion is not just a problem in dry climates; it can also occur in areas with adequate yearly rainfall due to pollution and poor management of surface waterways (Rodell et al., 2009).

The state Department of Mines and Geology's reports are the only sources of information on the research area. The Central Ground Water Board (CGWB 2007) issued a booklet on groundwater information for the Belagavi area. The studies covered in the regional reports from DMG and CGWB include hydrometeorological, water table conditions, and regional fluctuation investigations. There has been no research done on groundwater exploration, hydrogeochemistry, or groundwater recharge linked to the work. Remote sensing and GIS applications have been used for tasks unrelated to hydrogeology. However, geophysical/resistivity surveys for groundwater studies have been carried out by both public and private entities, but this data is not systematically examined. The objectives of the current study are framed using a variety of literature reviews, and the methodology and data products needed to accomplish the objectives are also identified.

## 2.2 REMOTE SENSING AND HYDROGEOLOGY

Using sensors onboard satellites to gather data about the Earth's atmosphere, seas, land surfaces, and ice sheets is known as satellite remote sensing. These sensors typically operate at wavelengths ranging from the visible (0.4 pins) to the microwave (0.25 m). The data is often gathered in two dimensions as a photographic image, such as high-resolution images from the metric camera carried on the space shuttle or as a digital data collection. The most effective and often used remote sensing tool for generating digital data on surface radiance is a multispectral scanner operated from a satellite platform. The scanner collects the unit cell's radiation, which then outputs a digital number (DN) or brightness value. The satellite sensor transmits the scanner data to the Earth receiving station. The top characteristics of a remote sensor are its spatial or terrain resolution, spectral resolution (the range of wavelengths it can measure), radiometric resolution (the total number of threshold values it can utilise), and temporal resolution. The maximum depth that high-frequency electromagnetic radiation, widely used by satellite remote sensing instruments, can penetrate is only a few metres, whereas groundwater has been discovered at depths of up to tens of metres. As a result, the ability of the remote sensing approach to provide precise information on the presence of groundwater is limited. Geological, morphological, topographical, and other surface factors influence groundwater intake, recharge, storage, and discharge to varying degrees; the study and analysis of these parameters yield important hints and information on the presence and recharge of groundwater. The different surface features typically observed in remote sensing data that act as a guide for groundwater investigation can be divided into two categories: first-order or direct indicators, or aspects directly related to groundwater occurrence and movement, and second-order or indirect indicators, or surface topography indirectly linked with groundwater regime (Singhal and Gupta, 2001). Small-scale pictures help identify landforms and understand regional settings, but image files or photographs are crucial for targeting and choosing drill sites and well locations. Since various objects reflect their distinguishing characteristics at various wavelengths, choosing the right spectral bands for remote sensing data is essential. In the pre-monsoon and post-monsoon periods, seasonal effects are seen in vegetation, land usage, river morphology, and soil tones. Temporal resolution is significant for studies on crop development, soil moisture, rainfall frequency, droughts, and floods. Pre-monsoon images allowed for a clearer examination of landforms, geological features, and lineaments due to the sparse vegetation cover. Due to their characteristic shape, tone, and pattern, surface water bodies such as streams, channels, lakes, etc., can be easily distinguished in optical and microwave data. Near-infrared(NIR), thermal-infrared(TIR), and microwave frequencies are better used to study soil moisture anomalies. While passive and active remote sensing data are utilised for a quantitative assessment of soil moisture fluctuations, visible, NIR, SWIR (short wave infrared), and TIR data are employed for a qualitative examination of soil moisture (Singhal and Gupta, 2001). The vegetation and its condition can also determine the presence of groundwater. Since leaf pigments control reflectance at these wavelengths, thermal and NIR bands are used to study vegetation density, health, and growth. The chemical or mineralogical makeup of groundwater and its level can be inferred from certain types of plants. As a result, groundwater research greatly benefits from characterising plant species using high-resolution aerial images and satellite imagery. River plains and fans, river valleys, point bars, dunes, moraines, etc., are common in soft sedimentary terrains, while rock outcrops are not present. Different rock kinds are recognised and interpreted based on related features and landforms. The lateral and vertical dynamics of groundwater are significantly influenced by geological structures such as lamination, foliation, folds, joints, and shear zones. In aerial pictures and satellite images, remote sensing offers geospatial data about the surface and near-surface characteristics for evaluation, interpretation, and mapping. Water resource management has experienced various paradigm shifts, from engineering to environmental perspectives and from top-down to bottom-up management. There is widespread consensus that a better balance between economic efficiency and environmental quality should be reached to utilise natural resources responsibly (Reitsma, 1996). Analysing water quantity, quality, and geographical and temporal changes within an area can enhance the integrated management of water resources (IWRM). A multidisciplinary management system using specific tools can be transformed into an integrated, multidisciplinary framework system using decision support systems. Remote sensing data can be used to determine various factors important for hydrology (Hochschild et al., 2003). Nevertheless, in recent years, microwave remote sensing has added a fresh perspective to the study of the subsurface. Remote sensing technology provides numerous indirect data elements that aid in locating groundwater. Lineaments are natural geological structures that are surface-appearing. Studying lineaments is crucial for understanding groundwater because they are surface reflections of weak zones under the Earth's surface and hence affect infiltration.

## 2.3 LINEAMENT CLASSIFICATION

From the perspective of groundwater study, geological lineaments must be distinguished since they may either encourage or inhibit subsurface flow (faults, joints, shear zones, Etc.). Furthermore, without any supporting information from field research or previous mapping, it is nearly hard to characterise faults (normal, reverse, and strike-slip), fractures (tensile, compressional, and shear), and joints (dilatational or compressional) in satellite imagery Data. The satellite image itself, however, can provide some supporting evidence. For instance, if some fracture patterns are connected to the main watercourse or flora lines, this is a sign of the current stress field and surface expression of groundwater movement (Waters et al., 1990). In challenging rock terrains, lineaments are crucial for groundwater recharging (Koch and Mather, 1997). In contrast to the visible lineaments, the most productive cracks may be hidden by thick alluvium or worn materials (Greenbaum, 1987).

## 2.4 HYDROGEOLOGICAL CONSIDERATION

Numerous researchers have shown lineament patterns (Boyer and McQueen, 1964) to represent joint and fault direction in various geological contexts. Others claim that joint mechanisms are different from those in places where folded rocks are present (Trainer and Ellison, 1967). Comprehending the three-dimensional characteristics, anticipated geometry, and scope of surface and subsurface linear geological features, as derived from structural geological data and insights typically obtained through field mapping, outcrop observations, or borehole logs, enhances the interpretation of lineament zones and their hydrogeological attributes (Brown, 1994). Although there is no clear-cut relationship between lineaments and zones of enhanced permeability, a fault with vertical movement will likely affect the depth of the groundwater water table on both sides of the fault line. The yield for a normal fault should be higher (Waters et al., 1990). The prevalence of high-density lineaments in arid and seen in arid regions speeds up the gravity-driven downward water movement and solutes along vadose zones, promoting recharge and diagenesis (Sigda and Wilson, 2003). Studies have shown that lineament density, or the number of clustered lineaments per unit area, has a more consistent and linear relationship with groundwater productivity than individual lineaments (Hardcastle, 1995). In groundwater inquiry, it is crucial to determine the orientation of open fractures using lineaments studies in conjunction with auxiliary information. However, the most accurate method involves determining the optimum groundwater flow paths using indications like spring orientations, strain directions, piezometric levels, etc. A mega-fracture, an extended lineament with significant vertical and lateral separation, is very significant and is linked to a smaller, more frequent, or dense fracture system, which increases the potential for groundwater recharge in the area (Kurtzman et al., 2005). An aquifer could represent a region of high specific yield within a zone of low specific yield as a mega-lineament or fracture zone. Because of the steady oblique illumination, the exclusion of some details, and the regional coverage, they are clearly expressed in satellite photos (Sabins, 1986). Lineaments can serve as witnesses to detect vertical fracture zones by crossing over fractured bedrock in the subsurface zone (Ouenes, 2000; Novak and Soulakellis, 2000).

## 2.5 GEOGRAPHICAL INFORMATION SYSTEM (GIS) AND GROUNDWATER MODELLING

When combined with additional data, remote sensing data gives a synoptic view of a region and is helpful for a comprehensive survey. An efficient software application that can handle geographical and non-spatial data and process, analyse, and model these data is needed to integrate remotely sensed data and other data effectively. Groundwater inquiry is made more efficient when geographical and non-spatial observations are combined with remotely sensed data in a GIS setting because the information from diverse hydrogeological characteristics is gathered collectively. Analysis, interpretation, and modelling of numerous data types are necessary for groundwater exploration. While hydrologic modelling deals with the transportation of water and its elements over the terrestrial surface and subsurface settings, GIS reflects the spatial aspects of the Earth. Hydrological modelling, which includes groundwater modelling, is typically related to the duration and variation in time length, but it also implies that topographical characteristics are uniformly distributed or have limited spatial variability.

On the other hand, the distribution of surface and subsurface factors is regarded by GIS as the primary foundation for analysis and modelling. It is possible to create a more accurate, logical, and realistic model of the continental and regional size by integrating GIS and traditional hydrological models. One of the critical contributions of GIS to groundwater modelling is the determination of hydrologic parameters. Realistic hydrologic models are intricate and consider four (gravity, friction, pressure, and inertia) forces (Maidment, 1993). As long as time variability is not preventable, groundwater modelling within GIS systems is possible. For the spatial depiction of flow, groundwater flow modelling that integrates hydrologic and GIS models are progressively gaining favour. Finite distinction and finite element codes require finding equilibria through a sequence of time-varying conditions, making them exceedingly complicated entities challenging to solve in a GIS setting, even in steady-state situations. GIS is more frequently and successfully used for hydrogeological modelling since it is less interactive with temporal variation than hydrology. In typical conditions, hydrogeological parameters are primarily static and unchangeable. Examining, interpreting, analysing, rating, and sometimes quantitatively evaluating numerous surface and subsurface characteristics that affect and regulate ground and surface water hydrology are all part of GIS-based hydrogeological modelling. In response to varied hydrological and hydro meteorological events, these models uniquely identify and assess geographical variation and variability. Thus, water infiltration, replenishment, potentiality, and productivity may all be predicted using GIS-based hydrogeological modelling under various meteorological and hydro meteorological conditions. Several parts of the freshwater analytical solution can be determined using GIS-based water balance modelling, which enables the estimation and planning of irrigation schedules, household supplies, and total groundwater demand throughout the year. Additionally, a catchment's role and significance in an aquifer can be evaluated using a GIS-based water balance model (Meijerink et al., 1994).

Given that hydrogeological modelling primarily deals with qualitative/categorical data, such as geological formations, soil classes, landform units, and land use classes. Because it is challenging to quantify these qualitative parameters, overlay and index techniques are frequently used in mapping-based decision-making to distinguish between good and unfavorable sites. Even quantitative factors like height, gradient, soil thickness, weathered-zone thickness, rainfall, etc., are characterized by placing them into interval classes to include them in the final themes. Along with other geological applications like seismic-zone demarcation, landslide hazard-zone delineation, and site selection for waste disposal, the GIS-based overlay and index method using rank and weight has been widely used in aquifer risk assessments, groundwater potential-zone demarcation, replenish delineation, etc.

## 2.6 GEOPHYSICAL PROSPECTING OF GROUNDWATER

With the expanding urbanization and industrialization of developing and developed countries, as well as the pressing need to improve food production, the demand for groundwater is rising very quickly. When the cost-benefit ratio is considered, it is proving exceedingly expensive to locate prospective groundwater resources by exploratory drilling.

Hydrogeological parameters, including aquifer thickness, borders, transmissivity, and storage coefficient, can be determined via geophysical surveys. Geophysical studies are necessary to establish the following:

- Subsurface characteristics, encompassing depth, thickness, and fluid saturation.
- Structural complexities including faults, voids, or karstic features.
- The occurrence of subsurface water represents both a potential water resource and a potential contamination source.

While infrequently employed in this discipline, the magnetic approach may occasionally be utilized to identify faults and shear zones that may impact the structure of groundwater flow. Electromagnetic and electrical techniques can significantly aid investigations into the environment and the Earth's interior. Differential or anomalous rock/soil physical qualities within the Earth's crust can be found using geophysical techniques, including gravity, magnetic, seismic, and electrical approaches. The primary objective of geophysical exploration is to gather information about the studied medium without causing disturbance (Kearey et al., 2002). Given the close relationship and quantifiability of soil materials and qualities through geoelectrical properties, methods based on electric properties are considered the most advantageous and promising. The characteristics of the geological material, the level of saturation, and the type of fluid all play a significant role in electrical resistivity. High electrical resistivities are found in dry soils and crystalline bedrock, whereas low electrical resistivities can be found in saturated sands, cemented aquifers, clayey materials, and saltwater-containing layers. Therefore, approaches based on electrical resistivity are practical for examining the geometry of aquifers and groundwater quality. he electrical resistivity of soil is influenced by several factors, including the level of water saturation (water content), the electrical properties of the fluid (solute concentration), temperature, composition of the solid components (particle size distribution, mineralogy), and the configuration of voids (porosity, pore size distribution, connectivity). Schlumberger (1920) first proposed Electrical resistivity measurements as a method for analyzing underlying rock masses.

Studies of the geometry and characteristics of aquifers need to be conducted more thoroughly due to the rising interest in groundwater resources in recent years. For many years, geophysics has been a helpful tool in these investigations, and as new tools and methodologies have been developed, geophysics' range of uses has grown. Many configurations, including those devised by Wenner (1915), Schlumberger (1920), Dipole-dipole (Al'pin, 1950), and Pole-dipole, have been used to conduct sounding and profiling in resistivity surveys (Yadav et al., 1997). For short investigations, the application of Wenner and Schlumberger arrays for standard profiling work is exceptionally straightforward and quick, but for more significant investigations, it is a very challenging task with such ample electrode spacing. The apparent resistivity exhibits variation as each electrode crosses the boundary of inhomogeneity or contact is another shortcoming of the data gathered in this manner (Keller and Frischknecht, 1966). As a result, pinpointing the exact position of the fractured zone may prove challenging. A five-electrode array is utilized in the offset Wenner variation of the Wenner configuration to lessen the impact of near-surface lateral inhomogeneities on the outcomes (Barker, 1981).

According to O'Connor (2003), the techniques can also be used to evaluate aquifer characteristics like transmissivity. The gradient array was covered in-depth by Kearey and Brooks (1984) and Telford et al. (1990). Environmental surveys and groundwater pollution mapping have recently used resistivity imaging surveys (Alile et al., 2008). Barker (1996) used the direct current resistivity technique to map groundwater pollution. Even though the weathered layer is deep and laterally changeable, rendering other electrical and electromagnetic methods ineffectual, Olayinka and Barker (1990) showed that resistivity imaging can be used in the hydrogeology of basement areas and mapping of heavily faulted areas. It has been demonstrated to be beneficial for mapping saline intrusion into an aquifer, identifying areas that require digging, and mapping the quality of the rock needed for quarrying (Dah lin et al., 1996; Barker, 1990). Expanding the electrode array around a central point is a step in the Vertical Electrical Sounding (VES) process. The apparent resistivity (resistance) is measured at each electrode separation increase. With the electrode separation, the investigation's depth deepens.

There are various techniques to search the groundwater since long. Surface investigations are cost effective and also success rate is also high. Among geophysical investigations electrical resistivity method is most generally used technique where Schlumberger configuration is most preferred. Though availability of surface water in many forms on the surface of the earth, there is a water crisis due to various causes made by nature as well by the anthropogenic activities. Groundwater study has advanced both in its thematic and cross-cutting areas (Pinder, 2012). In groundwater studies specially to measure aquifer geometry, mapping of the intrusive bodies, electrical conductivity of the subsurface, depth to basement, etc. geophysical techniques like magnetic, electrical and electromagnetic have been widely used since surface investigations are much simpler, fast and cost effective in relative to other methods (Chandra et al., 2008). In order to locate suitable site for groundwater extraction, physical properties and subsurface information was determined easily with low cost using geophysical survey such as electrical resistivity method and also for hydrogeological characterization (Sandberg et al. 2002, Sonkamble et al., 2014). During the early 1900s, electrical methods, specifically the resistivity method, were developed. However, their widespread utilization began in the 1970s, largely owing to the accessibility of computers for data processing and analysis. Electrical Resistivity methods have since been extensively employed in the quest for viable groundwater sources. Geophysical methods play a vital role in ground water exploration and provide indirect evidences for subsurface formations that indicate whether the formations are possibly aquifers or not. The presence of groundwater has largely to be deduced from the indicated geological structures. Geo-electrical prospecting is the important geophysical method. Available in groundwater exploration. Several scientists like Bhimasankaram et al. (1975 &1977); Benergy (1969); Bindumadhavan (1975); Zambre (1980); Bagdhan (1976); and Mani (1989) have applied the geo-electrical methods. Pantangay (1977) is of the opinion that, the electrical methods have greater advantage over other methods. Therefore, the electrical resistivity survey is the most popular and extensively used method for groundwater prospecting because of noticeable contrast in resistivity values between water saturated geological formations/structures and dry geological formations/ structures. This contrast is more prominent in hard rock terrains.

### 2.6.1 Groundwater Studies using Resistivity Methods

The thickness of the aquifer beneath resistive bedrock can be calculated using the resistivity method in groundwater investigation. Even groundwater quality, such as fresh, brackish, salty, or contaminated with harmful pollutants, can be determined using this technique (Zohdy and Bisdorf, 1990). It is abundantly clear from the geophysical literature (Alile et al., 2008) that resistivity surveys can be used effectively to prospect for groundwater in alluvial deposits. However, there are very few publications on the effective use of the DC resistivity method for groundwater investigation in karstic limestone regions. The connection between aquifers' electrical and hydrological properties has been discussed in the research. When Jones and Buford (1951) evaluated the formation factor and intrinsic permeability of specific samples of graded sand, they discovered that both variables increase with grain size. Croft (1971) established a relationship between the intrinsic permeability of an aquifer and the foundation factor for specific porosity ranges. Kelly (1977a) found a correlation between permeability, foundation factor, resistivity, and the aquifer's specific capacity. The past three decades have seen many authors attempt to establish an empirical and semi-empirical relationship between various aquifer parameters and the parameters obtained by geo-electrical soundings under various geological conditions (Mbonu et al., 1991; Yadav et al., 1993; Yadav, 1995). In addition to the findings mentioned above, Urish (1981) demonstrated an inverse association by leveraging the direct correlations between the foundation factor and hydraulic conductivity to explain the inverse relationship between porosity and hydraulic conductivity. In fractured crystalline bedrock, the relationship between average hydraulic conductivity and resistivity was demonstrated by Frohlich et al. in 1996. A few writers have reportedly used resistivity techniques to explore groundwater in a limestone aquifer with some degree of success (Vincenz, 1968; Seldar, 1954; Militzer et al., 1979). However, finding a narrow, water-bearing zone is typically quite challenging amid the enormous surrounding granite. It is nearly impossible to interpret resistivity data in a way that is hydro geologically useful due to the unconsolidated overburden and interbedded clay layers that complicate resistivity surveys. The theoretical responses of several models for various induced polarisation (IP) arrays were presented by Coggon in 1973. Furness (1994) provided theoretical responses for gradient arrays over resistive and conductive veins in terms of resistivity and chargeability. Sharma (1997) talked about using a gradient array and a mobile pair of potential electrodes to examine lateral variations in the subsurface's resistivity.

### 2.6.2 Different Resistivity Arrays and Groundwater Prospecting

Current electrical exploration techniques in groundwater explorations, mineral resource research, archaeology, and civil engineering studies have drawn much attention to one-dimensional (l-D) and two-dimensional (2-D) procedures. The most frequent method used to look into resistivity changes in the vertical direction is resistivity sounding (1-D). However, 2-D or 3-D imaging survey methods are the most effective for analysing lateral variations in subsurface resistivity, such as faults or dykes. A one-dimensional sequence of horizontal layers can be reasonably assumed when the lateral variation in the electrical characteristics of subsurface geological features is gradual. 2D and 3D surveys provide more accurate results for more complicated formations with lateral shifts over short distances.

### 2.6.3 Groundwater prospecting using RS and GIS technique

Due to the heterogeneity nature of subsurface and it is associated with some uncertainties, combination of multiple tools and methods like integrated approaches includes geophysical survey with remote sensing and GIS were used to diminish the ambiguities (Chandra et al. 2006; Sonkamble 2012). The theory and practice of geophysical method for groundwater investigations is documented by Bhattacharya and Patra (1968), Parasinis (1973), Kelly and Mares (1993), etc. Existing literature outlines the process of mapping potential groundwater prospect zones by generating individual thematic maps derived from satellite data, topographic sheets, field surveys, and accessible secondary data sources. All the thematic layers were converted into raster format and georeferenced to common reference point in the Universal Transverse Mercator plane coordinate system. Later all these layers were integrated with the help of "Spatial Analyst Module" of ArcGIS. The integration of various thematic maps describing favorable groundwater zones, into a single groundwater potential map has been carried out through the application of GIS. At the end groundwater potential zones has been classified by considering all the influencing factors and their importance in groundwater occurrence as (1) Excellent/Very good, (2) Good, (3) Moderate, (4) Average (5) Poor and (5) Nil.

## 2.7 QUALITATIVE ASSESSMENT OF GROUNDWATER

Water is scarce for humans and other living things, but it is imperative to nature. In the management of water resources, the quality of the water is just as crucial as the quantity. Since it depends on a specific intended application, quality is a function of physical, chemical, and biological characteristics and may be subjective. Numerous processes, such as the wet and dry deposition of atmospheric salts, evapotranspiration, interactions between soil and water, and rock and water, affect the composition of groundwater.

Because it is difficult to understand the intricate nature of the local hydrogeological conditions and the hydrochemical processes that take place in aquifers, advanced approaches must be used. Piper, 1944; Durov, 1948; Stiff, 1951) only used two-dimensional graphical approaches to analyse aquatic chemistry (Hem, 1970). In earlier research (Kim et al., 2003), graphical approaches such as Piper and bivariate diagrams with univariate statistical analysis were the main tools utilised for the interpretation of the physicochemical composition of groundwater. However, these techniques occasionally could result in false interpretations and conclusions (Kim et al., 2005). Multivariate statistical analysis can be utilized to get around this issue. This method is objective and can highlight information that is not immediately apparent by showing the natural correlation between samples and variables (Wenning and Erickson, 1994).

### 2.7.1 Statistical Methods in Groundwater Quality

Several researchers have carried out studies on the quality of groundwater with experimental and mathematical approaches (Jalut, et. al., 2018). Several methods such as statistical approaches are in practice for better analysis and interpretation of the large set of data (Sanchez-Martos et al., 2001). Multivariate statistical methods include various statistical methods for empirical study which gives an insight on physical as well as chemical characteristics of the groundwater system in space and time (Davis, 2002; Hussain et al., 2008). The traditional procedures to interpret the data of groundwater quality with normal graphs and plots will not describe the similarities among all the ions or samples simultaneously (Dalton and Upchurch, 1978). To overcome this drawback, the factor analysis method came into practice for an effective analysis in identifying such resemblances among the samples or variables. Extraction of the Eigen values and vectors from the matrix of correlations is included in the factor analysis (Davis, 1973). So, it is a practice in the multivariate statistical method which gives the interrelationships amongst the set of variables. The interpretation is constructed on loadings, factors and Eigen values. The factors are generated to decrease the complexity of the data. In recent years several works are being carried out using principal component analysis (PCA) for interpretation of the water quality variables, (Lohani, 1984; Winter et al., 2000; Gangopadhayay et al., 2001). PCA, multivariate statistical analysis, was primarily established as a device in the social sciences then it has been confirmed as much more effective in quality studies of groundwater (Reghunath et al., 2002; Subbarao et al., 1996; Khan, 2011).

Factor analysis has been a valuable tool in hydrochemistry, enabling the interpretation of observed interrelationships between variables, revealing underlying structures, evaluating the spatiotemporal distribution of pollutants under study, and assessing controls on groundwater composition (Matalas and Reiher, 1967). While factor analysis can effectively identify various pollution variables, the subjective nature of interpreting these factors in relation to the authentic regulating sources and processes remains a challenge. Numerous geological disciplines, including petrography (Saager and Esselaar, 1969), geochemistry (Reeve et al., 1996), and environmental geology, have employed factor analysis as a methodology (Voudouris et al., 1997). Recently, many scholars have started using factor analysis and cluster analysis as a part of multivariate statistical analysis to evaluate the quality of groundwater (Love et al., 2004; Shrestha and Kazama, 2007). In general, cluster analysis demonstrates the overall similarity of variables in the data set and links inter-sample similarities to indicate groupings of samples (Massart and Kaufmann, 1983). Principal components analysis (PCA), one of the most effective and widely used approaches for lowering the dimensionality of colossal data sets without significantly reducing the amount of information retained, is a type of factor analysis. Because it can reveal the involvement of specific molecules among various factors that influence an outcome, it enables one to evaluate the relationships between variables (Meglen, 1992). Various multivariate statistical approaches are applied to interpret complicated data matrices and gain a deeper understanding of the water quality and ecological state of the system under study. It also gives a valuable tool for the responsible management of water resources as well as a quick resolution to pollution issues (Reghunath et al., 2002; Simeonov et al., 2004). It also permits the identification of potential factors/sources that may influence water systems.

### 2.7.2 Water quality Index

Water Quality Index (WQI), is computed from experimental results and drinking water standards and it is for suitability for drinking purposes. Several scholars have attempted to improve many groundwater quality indices (GWQIs) for assessing groundwater quality (Islam et al., 2018). Initially, the concept of WQI was suggested by Horton (1965) and Brown et al. (1970). Later, various methods have been developed by many authors (Debels et al., 2005; Saeedi et al., 2010; Tsegaye et al., 2006). For the classification of groundwater, WQI is one of the criteria with the use of standard parameters for water characterization and also for transformation of the large set of water quality data into a single value and it also signifies the water quality level (Bordalo et al., 2006; Sanchez et al., 2007). It uses standard parameters for water characterisation and converts a vast set of water quality data into a single value. By considering various factors affecting groundwater quality, numerous writers have classified groundwater samples from the BW and HP into various clusters. Hierarchical clustering is one of many techniques frequently used for groundwater research (Subbarao et al. 2013; Bloomfield et al. 2013; Pathak & Dodamani 2018).

### 2.8 Groundwater recharge zones/Site suitability for groundwater recharge

Yadav et.al. 2012 and Mukherje, D. 2016, have discussed on various methods for artificial groundwater recharge some of which are commonly adopted methods and are classified as direct surface methods, direct subsurface methods and indirect methods. Regarding recharge areas, type of lithology which is exposed in the area and its character are most important since other factors are greatly dependent on it (Ghosh et al., 2016). Edet et al. 1998 explained that as some hydrogeologists neglected this factor since they were considering drainage and lineaments as a part of lithology. Later other researchers (Magesh et al. 2012; Acharya and Nag 2013) incorporated this geology feature since it strongly influences infiltration. With this reason it is essential to incorporate this factor for groundwater recharge studies. Doll et al., 2002 explained that surface with comparatively moderate sloping terrains, influences more recharge, so lower the slope, the better the recharge. In the year 2007, Dinesh Kumar et al said geomorphology factor of an area is analyzed based on the type of landforms, associated vegetation, areal extent, etc. hence field survey is very essential to classify the various landforms.

The literature indicates that obtaining cloud-free satellite data is crucial for generating Lu/Lc maps, and the availability often depends on the organization from which the data is sourced for a specific area. Major organizations such as national remote sensing centre(NRSC), national aeronautics and space administration(NASA), BHUVAN website, among others, provide such data. In the Indian context, according to existing literature, the preferred datasets are derived from linear imaging self-scanning scanner (LISS) data, offering resolutions like 72.5m, 36m, 23.6m, and 5.8m, sourced from satellites such as IRS, CARTOSAT, and RESOURCESAT. Some studies suggest enhancing resolution by merging panchromatic (PAN) data with LISS-III and LISS-IV. Additionally, authors have considered Landsat data, which offers 30m resolution and, in some cases, merged it with PAN data, providing 15m resolution. However, the usage of LISS-IV data has been limited in available literature due to its restricted availability; it has only been utilized sparingly in recent years as it's not freely accessible.

The permeability of an area is primarily contingent on its topmost surface layer, typically the soil layer. Therefore, the movement of runoff or surface water into the aquifer system largely relies on the soil type and its texture (Anbazhagan et al., 2005). The formation of soil types is influenced by various factors such as topography, parent rock, climate, and geological processes, all of which play crucial roles in runoff and groundwater recharge (Rashid et al., 2012). Soil composition and depth significantly contribute to the recharge process. According to various studies, data regarding soil and its depth has been sourced from NBSS LUP in Indian literature to understand these aspects.

The drainage factor is primarily influenced by the underlying lithology, making it a crucial indicator for identifying water infiltration, according to Shaban et al. (2006). Ghosh et al. (2016) also highlighted that higher drainage density corresponds to a lower recharge rate and vice versa. Regarding the extraction of a more suitable drainage pattern, many researchers prefer manual extraction over patterns generated from satellite imagery, as advocated by Tribe (1991), Ichoku et al. (1996), and Martinez-Casasnovas and Stuiver (1998).

Lineaments are hydrogeologically more significant factors since they offer the paths for groundwater drive. Shaban et al. 2006 said, for groundwater flow the connected lineaments create subsurface path. Lineaments are associated with fractures and faults which causes secondary porosity and permeability which are indicator of the suitable recharge zones (Dinesh Kumar et al. 2007). Higher the number of lineaments more the paths for groundwater flow and can expect more infiltration which improve the recharge capacity. In many of the landscapes especially in hard rock terrains, lineaments are key factor in groundwater recharge studies (Rashid et al. 2012). Groundwater potential zones are associated with lineament zones as suggested by Srivastava and Bhattacharya (2006). So based on groundwater potential zones we can identify the recharge zones.

Therefore, upon reviewing diverse literature sources, the subsequent thematic layers are frequently employed to delineate potential sites for groundwater recharge or groundwater potential zones.

**Lithology/geology + Slope + Geomorphology + Lineament + Land use/Land cover(Lu/Lc) + Soil type + Slope + Drainage + Rainfall + Groundwater contour**

The literature demonstrates that generating output maps for groundwater potential zones, site suitability for groundwater recharge, and water quality indexes through integrated layers can serve various purposes. These outputs can be beneficial in developing sustainability schemes for groundwater management while aiding in the delineation of groundwater potential zones.

### 2.8.1 Artificial groundwater recharge

Groundwater is naturally replenished through a process known as recharging, which involves rainfall infiltration, watercourses, lakes, irrigation return flow, and seepage via natural hydraulic gradients (El-Rawy et al 2021). Nonetheless, prolonged excessive pumping beyond the aquifer's capacity may cause an imbalance, resulting in the overuse of its storage and an ongoing decrease in groundwater levels. A strategy to counteract declining water levels involves the implementation of artificial groundwater recharge. Artificial recharge (AR) deliberately channels surface water underground to supplement natural groundwater reservoirs and rehabilitate aquifer systems. However, unregulated human-induced recharge can result in issues such as waterlogging and groundwater contamination. The historical origins of artificial aquifer recharge methods trace back to the late 19th century, with the inception of the first infiltration basins appearing in Sweden in 1897 and in France in 1899 (Dillon et al., 2019).

Guidance pertaining to the hydrogeological and engineering facets of groundwater AR has been provided by Bouwer (2002). Various objectives and benefits of enhancing aquifer recharge methods are discussed in (Dillon, P. 2005), while a comprehensive review of artificial groundwater recharge's current knowledge is available in (Jódar-Abellán et al. 2017). Moreover, Hao et al. (2014) illustrates the utilization of groundwater simulation models to evaluate the viability and efficiency of various artificial recharge scenarios. Internationally, artificial recharge is recognized as a method to raise groundwater levels and improve water quality within a wide range of groundwater aquifers (Hassan et al., 2021). The work by (Shafa et al. 2023) optimized surface and groundwater resource utilization, incorporating artificial recharge systems to boost water resource sustainability and reduce associated environmental issues.

Unintentional recharge, known as uncontrolled recharge, is associated with human activities. In rural regions, this recharge occurs through canal leakages, irrigation return flows, and is influenced by alterations in land use and cover. Conversely, controlled artificial recharge focuses on meticulous considerations and monitoring to regulate the recharge rate. Considering the repercussions of uncontrolled recharge, it's suggested that future efforts should transition from artificial recharge (AR) towards managed aquifer recharge (MAR). MAR aims to store water deliberately in the aquifer for future recovery (Abd El Moneam, 2023).

Storing water underground through artificial recharge offers the advantage of minimal evaporation from the aquifer, a significant benefit. Additionally, economic and various other aspects related to recharge tend to be advantageous. Due to these reasons, the adoption of artificial recharge is swiftly growing across numerous regions worldwide. Bouwer (2002) extensively discusses these aspects and also he has addressed artificial recharge systems across various categories, including surface infiltration, vadose-zone infiltration, direct recharge or injection wells, as well as combination systems.

# CHAPTER 3

# GEOLOGY AND GEOMORPHOLOGY

## 3.1 INTRODUCTION

Natural resource studies are not typically heterogeneous in nature because they frequently depend on numerous other factors. No exception applies to groundwater, which is both directly and indirectly influenced by the region's geology, geomorphology, climate and other drainage characteristics. Along with climatic and meteorological factors like precipitation ratios, temperature, humidity, rainfall intensity etc, and geological & geomorphological aspects like stratigraphy, lithology, structures, soil, slope, drainage parameters etc. have a crucial role in defining the ground water conditions.

A comprehensive geological investigation was carried out aimed at delineating the precise lithological sequence, identifying various rock formations, and categorizing them based on their groundwater potential and the area's structural framework. These aspects are vital in understanding the existing groundwater conditions (Thorat et al., 1990). The hydrological traits of the aquifer are depending upon the composition of the rocks and soils constituting it. Geology significantly governs a crucial parameter, the quality of the groundwater sourced from that aquifer. A fundamental grasp of the terrain's geological composition offers valuable insights into both the occurrence and quality of groundwater. This chapter accentuates the broader geological landscape of Karnataka, focusing particularly on the characteristics of lithology, soil studies, geomorphology and their specific attributes of the Kanavi Halla Sub Basin (KHSB) in Bailhongal, Saundatti and Gokak taluks of Belagavi district.

## 3.2 GEOLOGY

The geology of the region plays a prominent role in shaping the groundwater basin, especially the boundary conditions for the geological units. The major litholog in the area units are Gneiss, quartzite and basalt

### 3.2.1 Geology of Karnataka

Karnataka, which is a portion of the Indian Shield, is made up of rock formations that are between 3300 to 5 million years old. The remaining area is dominated by Archaean-Proterozoic rocks, with the exception of a small coastal strip of around 5000 sq. km. of Tertiary and Quaternary sediments and another 31,250 sq. km. of Deccan basalts. The geological history of Karnataka has a wide range of lithological diversity from older Archean Dharwar craton to recent soil formations. The middle Proterozoic to more recent sedimentary basins, greenstone belts, intrusive volcanics and the Dharwar batholith (dominantly granitic) make up the craton (Ramakrishnan and Vaidyanadhan, 2008)(Figure3.1).

The Mysore Plateau, which is geologically a part of the Dharwar craton, is made up of gneisses, granulites, and belts of greenstone-granite. Greenstone belts are basically composed of sedimentary sequences from meta-volcanoes that are encircled and divided by Peninsular Gneiss. These give ways to the granulite suite of rocks near the southernmost point of the craton. The craton preserves a billion-year orogenic history from 3400 million years. to 2400 m.a. The northern half of the craton, which is also covered by Deccan basalts, is occupied by epicratonic or intracratonic sedimentary basins known as Purana basins. It is clear that the litho-sequence is younging from south to north. The Dharwar craton is bounded by the Arabian Sea in the west, the high-grade terrains of Tamilnadu and Kerala in the south, the crescent shaped Cuddapah basin (1600 Ma), and a significant portion of the gneissic terrain in the east. The northern extensions of the cratonic block are obscured by the cover of the Mesozoic-Tertiary Deccan Traps in the north. The Dharwar craton, which consists of a series of subparallel schist belts embedded in a matrix of polyphase gneisses surrounded by granites to the east and granulites to the south (Radhakrishna and Naqvi, 1986; Radhakrishna and Ramakrishnan 1988; Ramakrishnan & Vaidyanadhan 2008).

Rocks of Dharwar Supergroup are represented mainly by sericite phyllite, quartzite, quartz-chlorite schist, quartz- chlorite-amphibole schist, meta greaywacke argillite, banded mangentite quartzite/ banded ferruginous quartzite and limestone. Meta greywackes parts are intruded by granites, basic, ultrabasic sills and dykes. The rocks have trends varying from NNW-SSE to NW-SE with high angle eastward dips. At the central part of the district the rocks of the Dharwar Supergroup are unconformably overlain by sedimentary sequences of Kaladgi Supergroup of Upper Proterozoic age. Sandstones are the most abundant rock type in the Kaladgi sequence. Their mature sandstone character is a distinguishing feature indicating crustal stability, extensive reworking and intensive weathering. A good portion of the sandstone can be called quartz arenite and the rest being classed as quartzite-wacke. Dips are generally low and crossbedding and ripple marks are common. Following the quartzites are well-developed sequence of argillites which are brown to purple in colour in prominent bedding planes. They are locally rich in carbonate Beds of dolomite are well-developed and are of different shades of bluish to dark-grey and black. The rock is traversed by parallel band of chert. Thick beds of limestone showing intricate fold pattern are prominent member in the Kaladgi Sequence and are well exposed. Stromatolite structure so common in the dolomites are absent in limestone which generally occupies low ground and is often covered by black soil. The Kaladgi Sediments comprises a thick sequence of shallow marine clastics and carbonates. These sediments are classified into a lower Bagalkot Group and an Upper Badami Group. The Bagalkot Group of sediments represented by argillite with limestone, dolomite

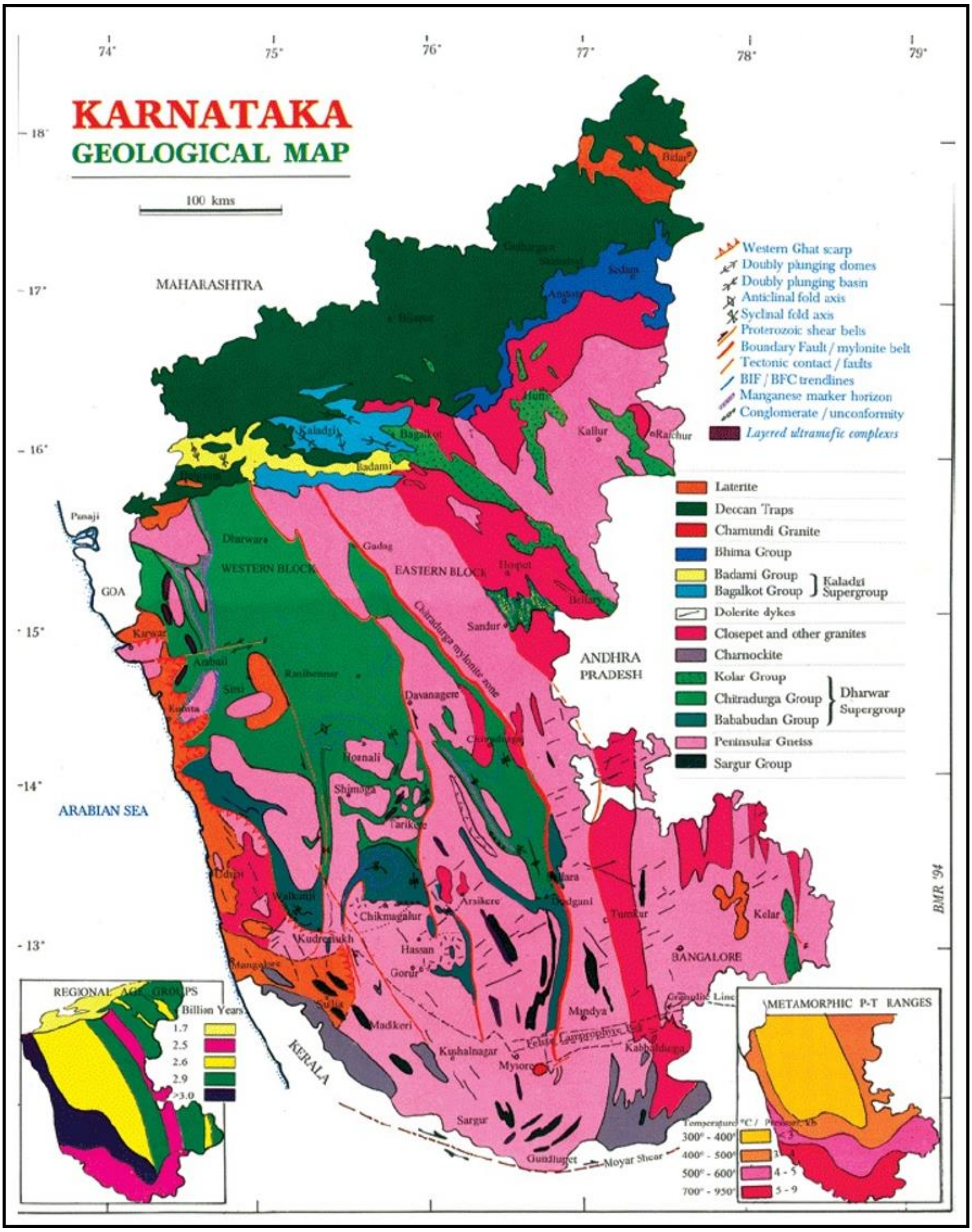



Figure 3.1 Geological map of Karanataka (Modified after Radhakrishna and Vaidyanadhan, 1994)

and quartzite are folded whereas the Badami Group of sediments are not folded. Deccan Traps overlie the Precambrian rocks in the south western part covering parts of Khanapur and Belgaum taluks and account for about 259 m of thickness. They are tholetitic, continental basaltic lava flows of Cretaceous- Eocene age. The basaltic flow is horizontal to Sub-Horizontal in deposition and are well-jointed. Extensive lateritisation during the tertiary period has given rise to thick laterite profile on all the litho-unit.

Based on the significant change in lithology and age variations, the Dharwar craton has been subdivided into eastern and western block (Swami Nath et al. 1976). The Chitradurga Shear, a low angle thrust that becomes shallow at deep and a steeply dipping mylonite zone, (Chadwic et al. 1992) serves as the boundary between these two blocks. Dharwar craton is one of the important craton in Indian shield. Many researchers studied the Dharwar craton in different aspects and made divisions of the craton into three blocks like western, central and eastern, based on their grade of regional metamorphism, degree of melting, geochemistry, petrological studies and U-Pb Zircon ages and Nd isotope data (Jayananda et al., 2013 a,b; Peucat et al., 2013; Balakrishnan et al., 1999; Ugarkar and Nyamati 2002; Manikyamba et al 2008,2014; Manikyamba and Kerrich 2011; Ugarkar et al, 2000, 2013 and Dey 2013).

Western Dharwar craton comprises of older larger group and upper Dharwar super group. the Dharwar's and the Sargur's are much more widely expressed in the western block. The Sargur group comprises of volcano-sedimentary rocks like komalites, basalts, andesites, dacite, rhyolites, BIF, conglomerates, sandstones (Ramakrishnan and Vaidyanadhan 2010, Tushipokla and Jayananda 2013). The Western Dharwad craton is bordered to the north by the southern granulite terrain, to the east by the eastern Dharwar craton and to the west by the Arabian Sea. The Cretaceous Deccan traps and newer sediments cover the remaining boundary to the north. Western Dharwar craton comprises of Holenarsipur, Bababudan, Shimoga-North Kanara and Chitradurga-Gadag schist belt. The supracrustal rocks of the sargur group have undergone granulite facies metamorphism in the southern region of Carton. The Sargur group is made up of a variety of volcanic and sedimentary lithologies including Pelites, Quartzites, impure Carbonates, iron formations, intrusive ultramafic-mafic and gabbro-anorthosite complexes.

The eastern Dharwar craton have three main greenstone belts which are Ramagiri-Penakacherla-Sirigeri-Hunagund, Kolar-Kadri-Jannagiri-Hutti belt and

Velugallu-Raichur-Gadwal super belt mainly comprising of mafic-ultramafic rocks, quartzite, siliceous schists, BIF, metagrewacke, conglomerates, fuschite quartzite, polymictic conglomerate, phyllite limestone. While the eastern block has fewer supracrustals, many of them have discrete granite bodies, especially the elongate N-S Closepet granite and a collection of multiple different plutons of the late Archean or early Proterozoic age, which traverse the eastern block near its western extremity. The Deccan Traps, the Bastar Craton, the Eastern Ghats Mobile Belt and the South Granulite Terrain all encircle the Eastern Dharwar Craton on its northern, eastern and southern boarders respectively (Ramakrishnan & Vaidyanadhan 2008 (Table 3.1).

The Proterozoic Kaladagi supergroup is located on the northern part of Dharwar craton (Viswanathiah 1979, Jayaprakash et al 1987). The angular unconformity divides the older Bagalkote group and younger Badami group. The Bagalkote group is about 3600 m thick with Mesoproterozoic Lokapur subgroup and Simikeri subgroup mainly consisting lithologies like quartzite, argillite, chertbreccia, carbonates and dolomites. The upper neoproterozic Badami subgroup mainly consisting of conglomerates, sandstone, arenite, Shale, limestone rocks (Vishwanathiah 1979, Jayaprakash et al 1987, Kale et al 1999).

The northern part of Karnataka covers the deccan basalt which is the largest continental flood basalt in the world and which covers around 5,00,000 sq km (Ramakrishnan & Vaidyanadhan 2008; Valdiya 2016).

Table3.1 Lithostratigraphic succession of Kaladgi Basin (Modified after Viswanathiah, 1977; Jayaprakash et al., 1987; Kale et al., 1999).

| | Group | Subgroup | Formation | Member |
|---|---|---|---|---|
| | | **Deccan traps** | | |
| | | ***Angular and erosional unconformity*** | | |
| KALADGI SUPERGROUP | **Neo-Proterozoic**<br>BADAMI | | ➢ Konkankoppa Limestone<br>➢ Halkurki Shale<br>➢ Cave Temple Arenite | • Gokak Sandstone<br>• Kendur Sandstone<br>• Torgal Conglomerate |
| | | | ***Angular Unconformity*** | |
| | **Meso-Proterozoic**<br>BAGALKOT | **SIMIKERI** | ➢ Lakshanhatti Dolomite<br>➢ Niralkeri Chertbreccia<br>➢ Arlikatti Argillite<br>➢ Muchkundi Quartzite | • Tulasigeri Quartzite<br>• Bevinmatti Conglomerate |
| | | | ***Disconformity*** | |
| | | **LOKAPUR** | ➢ Petlur Carbonates | • Chikshellikeri Limestone<br>• Chitrabhanukot Dolomite |
| | | | ➢ Mahakut Chertbreccia | |
| | | | ➢ Yadhalli Argillite | • Yaragatti Calc. Shale<br>• Jalikatti Phyllite<br>• Manoli Ferrug.Shale |
| | | | ➢ Saundatti Quartzite | • Timmapur Quartzite<br>• Almatti Quartzite<br>• Salgundi Conglomerate |
| | | ***Angular and erosional unconformity*** | | |
| | | **PRECAMBRIAN BASEMENT COMPLEX(PBC) Granitoids, Gneisses and Metasediments** | | |

### 3.2.2 Geology of the study area

The geology of the study area is primarily composed of gneiss, quartzite and basalt, with some limestones and sandstone. The region is composed of limestone, sandstone and quartzite from the Upper Precambrian kaladgi group as well as Deccan Basalt, which is tertiary to Mesozoic in age. The gneiss belongs to Peninsular Gneissic complex group of Archean age. The lithostratigraphy of the area is given in Table 1 (GSI, 2005; Ramakrishnan and Vaidyanadhan, 2010; CGWB 2016-17). The Kanavi Halla Sub Basin (KHSB) area is dominantly covered by Basalt and arenite with shale and Limestone (Figure 3.2).

Hard rocks occupy a major part of the study area. Most of these rocks have poor capacity of storing and transmitting water, except through favourable zones and at favourable locations. Aquifer systems encountered are, therefore, limited in nature. Groundwater occurs both in weathered, jointed and fractured zones. Groundwater occurs in all weathered formations of the study area under phreatic conditions and in fractured and jointed formations under semi-confined conditions. The southern region of the area contains basalts from the Tertiary to Mesozoic periods, while the central and eastern parts are characterized by the presence of arenite/sandstone and quartzite from the Proterozoic Kaladgi formation. Additionally, the lower stratigraphic levels of the study area feature Archean gneiss (Table 3.2).

Table 3.2. Geology of the area (Ramakrishnan and Vaidyanadhan, 2010 after GSI 2005)

| **Litho-units** | **Stratigraphic age** | |
|---|---|---|
| Soil Cover | Recent | |
| Deccan basalts | Cretaceous to tertiary age/ tertiary to Mesozoic (CGWB 2016-17) | Deccan Trap Basalt |
| Limestones, Sandstones & Quartzities | Proterozoic age, Upper Precambrian | Kaladigi Series |
| Gneisses | Archean age | Peninsular Gneissic Complex |

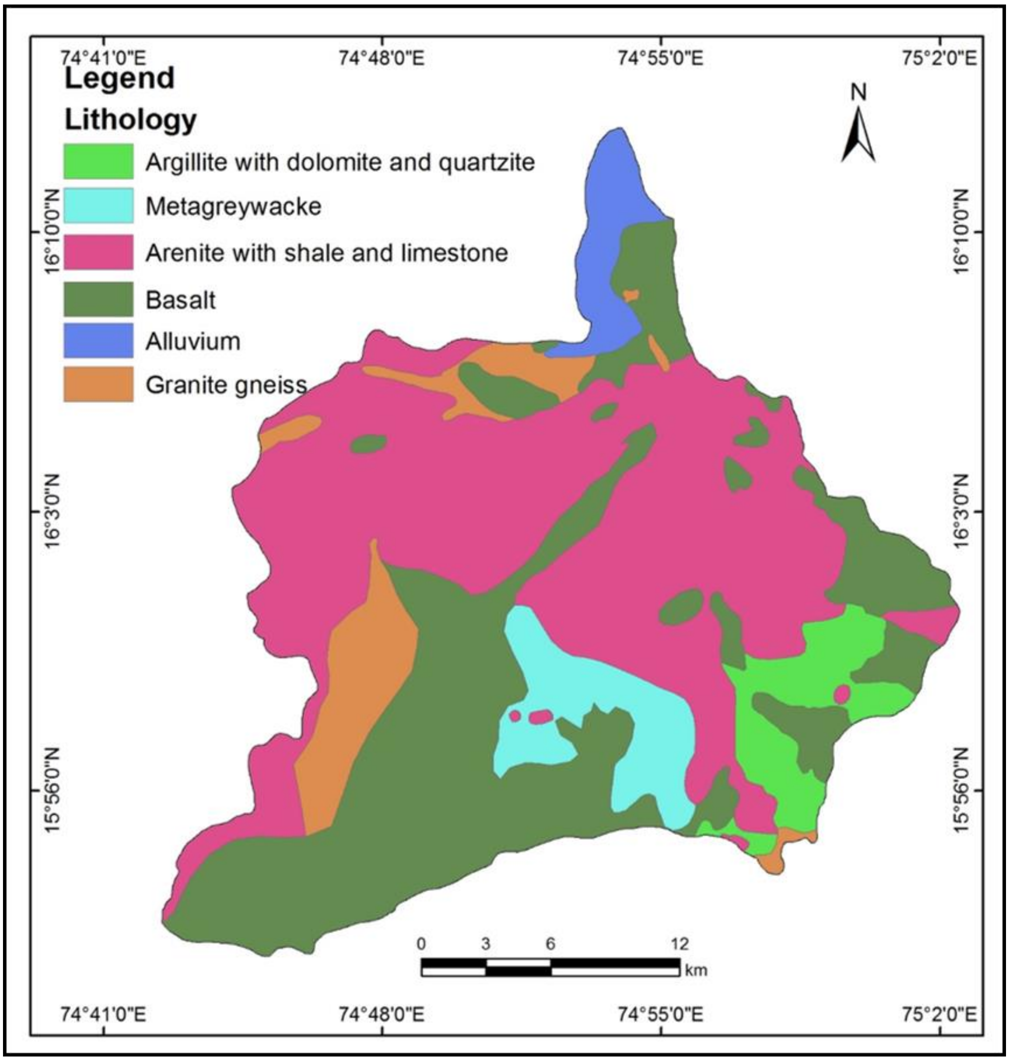



Figure 3.2 Geology of the Study area

The geological composition of the KHSB comprises approximately 45% Arenites, with basalts constituting about 34% as the predominant lithology. Additionally, it consists of around 7% Granite gneiss, 6% Metagreywacke, 5% Argillite with dolomite and quartzite, and 3% Alluvium. Groundwater is primarily hosted within the weathered zone, occupying fissures, fractures, and pore spaces within the weathered rocks. The lithology map of the study area has been constructed using a published Geological Survey of India (GSI) quadrangle map, which is at a scale of 1:25,0,000. Furthermore, lithology maps obtained from the Karnataka State Remote Sensing Application Centre (KSRSAC) at a scale of 1: 50,000 have been collected, geo-referenced, and then digitized. The classification of lithological features within the study area is illustrated in Figure 3.2, while area statistics are presented in Table 3.3.

Table 3.2 The categories of lithology and their corresponding area Statistics.

| Sl. No. | Lithology Classes | Area ($km^2$ ) | % |
|---|---|---|---|
| 1 | Argillite with dolomite and quartzite | 37.37 | 5.4 |
| 2 | Arenite with shale and limestone | 307 | 44.75 |
| 3 | Alluvium | 22.2 | 3.2 |
| 4 | Basalt | 229.52 | 33.45 |
| 5 | Metagreywacke | 40.92 | 5.96 |
| 6 | Granite gneiss | 49.64 | 7.2 |
| | **Total** | **686** | **100** |

### 3.3 SOIL TYPES OF THE STUDY AREA

Soil emerges from the breakdown of parent rocks due to temperature fluctuations and hydration effects caused by weathering. Soil formation is a continuing process subjective by aspects such as climate, landscape, parent material/rock, vegetation to a limited extent, organisms, and time. Soil properties predominantly dictate the quantity of groundwater replenishment, retention, and release. The soil's ability to hold water varies across different types due to their variable textures. Soil is the top most layer of earth’s crust and it is natural, heterogeneous, and dynamic mixture of mineral particles, water, air, organic matter and living organisms found on the Earth's surface.

Soil significantly contributes to enhancing groundwater recharge and influences its quality. The soil of the study area broadly comprises of red soils and black soil types. The study area consists of Alluvial black calcareous clayey soil, Alluvial loamy soil, Black clayey soil, Mixed black clayey, Brown loamy soil, Red gravelly clay soil, Red gravelly loam soil and Red loamy soil. The depth of soil varies considerably across different locations, ranging from a few centimeters to meters deep. Below is a description of the soils present in the study area. The classification of soil types within the study area is illustrated in Figure 3.3, while area statistics are presented in Table 3.3.

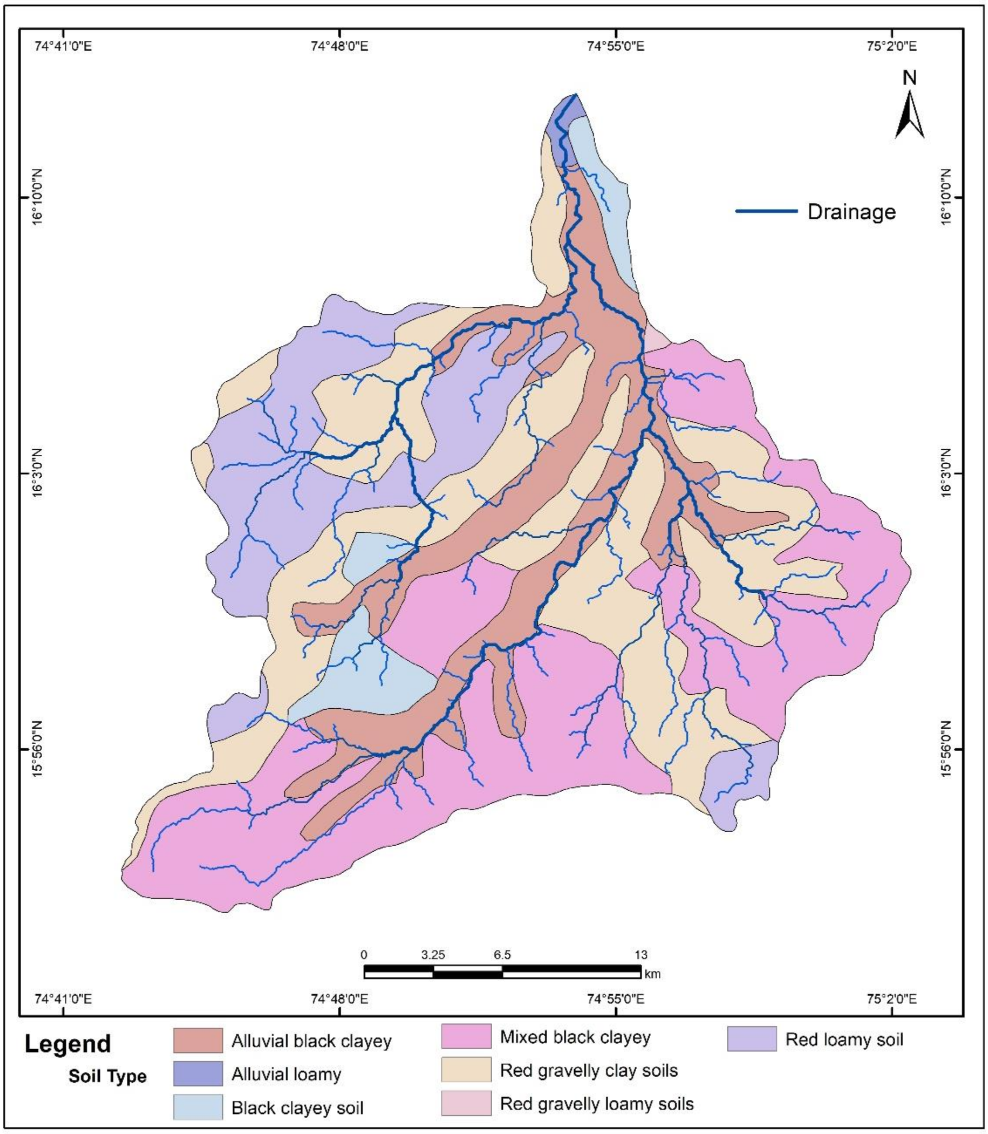



Figure 3.3 Soil Types of the Study Area along with drainage pattern (After NBSS & LUP)

### 3.3.1 Alluvial black calcareous clayey soil

This soil variety originates from sediment deposition carried by streams and rivers. It typically contains a high proportion of clay and a variety of minerals, including calcium carbonate (calcareous). Often, it can be found in river valleys or floodplains where sediments gradually accumulate.

Due to its high clay content, this soil type often exhibits low permeability, impacting water penetration and drainage, resulting in slow movement of water within the soil profile. While its moisture retention capability can aid groundwater replenishment, the slow permeability may hinder rapid recharge rates. In times of heavy rainfall, rapid saturation of the soil's water absorption capacity can lead to increased surface runoff. These soils are settled over the alluvium placed by the Kanavi halla and its lower order drainages. They are restricted in extent and thickness (Figure 3.3)

### 3.3.2 Alluvial loamy soil

Alluvial loamy type of soil comprises of northern tip of the study area where Kanavi Halla joins the river (Figure 3.3). This soil variety is formed by the accumulation of silt, sand, and clay transported by rivers and streams, commonly located in regions adjacent to riverbanks or floodplains. Recognized for its balanced mixture of sand, silt, and clay particles, this soil type fosters favourable conditions for irrigation practices and robust plant growth.

This soil type possesses moderate permeability, facilitating proper water infiltration and drainage while maintaining enough moisture for plant growth and preventing waterlogging. Its well-balanced texture promotes effective infiltration, aiding groundwater recharge by enabling water to percolate through the soil profile. Its excellent water retention capability reduces surface runoff, particularly during periods of heavy rainfall.

### 3.3.3 Black clayey soil

Black clayey soil, commonly referred to as black cotton soil, is identified by its dark hue and abundant clay content. It is widespread in numerous global regions, especially those with tropical or subtropical climates. Due to its high clay content, this soil type exhibits low permeability, making it susceptible to waterlogging. Its limited permeability and sluggish infiltration characteristics may lead to surface runoff during periods of heavy rainfall. This type of soil covers in south western part and also some patches in northern part of the study area (Figure 3.3).

### 3.3.4 Mixed black clayey and Brown loamy soil

This soil type results from a blend of both black clayey and brown loamy soil, formed through the gradual mixing of diverse soil types due to various geological processes.

The presence of loamy soil alongside black clayey soil contributes to improved permeability, promoting good infiltration and drainage while reducing the risk of waterlogging. During rainfall, surface runoff in this mixed soil type may be moderate, influenced by the diverse characteristics and the distribution of each soil type within the soil profile of mixed black clayey and brown loamy soil. Surface runoff may be moderate since it has varied characteristics of mixed soil type during rainfall. It also depends upon the proportion and distribution of each type of soil in a soil profile of mixed black clayey and Brown loamy soil. It is noticed in eastern and southern part of KHSB.

### 3.3.5 Red gravelly clay soil

This soil type displays a reddish hue and coarse texture due to its gravel content and the inclusion of clay particles. It's a mixture comprising gravel, clay, and a combination of sand and silt. The presence of gravel facilitates easy infiltration and improves permeability in contrast to fine clay particles. However, the clay content moderates permeability to a certain extent, contingent upon the proportions of clay and gravel within the soil profile. Consequently, the gravel mitigates surface runoff and fosters infiltration during rainfall, subject to the equilibrium among gravel, clay, and other constituents. This type of soil noticed mainly in central part of KHSB and also some pockets in western and northern part of the study area (Figure 3.3).

### 3.3.6 Red gravelly loam soil

Similar to red gravelly clay soil, red gravelly loam soil differs in that it contains loam instead of clay. However, the remaining characteristics are akin to those of red gravelly clay soil. A small patch is seen in north-eastern part of KHSB (Figure 3.3).

### 3.3.7 Red loamy soil

Red loamy soil occupies western part of the study area and it is distinguished by its reddish hue and primarily consists of substantial amounts of silt and sand, with varying proportions of clay (Figure 3.3). Its notable sand content facilitates easy water infiltration, promoting good permeability. However, the presence of clay moderates this permeability to some degree. Due to the prevalence of sand particles, red loamy soil exhibits comparatively lower surface runoff during rainfall than soils with finer particles, aiding in water absorption.

Table3.3 Categories of soil types and corresponding area statistics.

| Sl No | Soil type | Area ($Km^{2)}$ | Area (%) |
|---|---|---|---|
| 1 | Alluvial black calcareous clayey soil | 131.50 | 19.17 |
| 2 | Alluvial loamy soil | 3.36 | 0.49 |
| 3 | Black clayey soil | 30.62 | 4.46 |
| 4 | Mixed black clayey and Brown loamy soil | 213.63 | 31.14 |
| 5 | Red gravelly clay soil | 203.34 | 29.64 |
| 6 | Red gravelly loam soil | 1.03 | 0.15 |
| 7 | Red loamy soil | 102.52 | 14.94 |
| | **Total** | **686** | **100** |

These soils vary in texture and depth, depending on the parent rock type, physiographic settings and climatic conditions. The black soil predominates the Deccan trap terrain and the red soils are found in the granitic terrain region. Clayey and loamy soil predominately covers the study area. Along the drainage's streams, alluvial black calcareous clayey soil can be found which are dark greyish-brown to very dark greyish-brown in colour and have a clayey texture. These are derived from the weathered products of basalts and limestone are darker in valets than in highlands. Their texture varies from loam to clay with low to moderate infiltration characteristics. The study area's southern and southern-eastern regions are covered in a mixture of black clayey soil and brown loamy soil. Red gravelly clay soil, red loam soil, mixed black and brown loam soil, and red gravelly loam soil are among the other various types of soil in the area of study with silty - clay to clayey loam texture. These soils are derived from gneisses, Schists and sedimentary rocks. Red soil having high infiltration characteristics are confined to uplands whereas black soils of poor to medium infiltration characteristics occur in valley and low lands whereas the alluvial soils are limited to the tributaries and have limited extent and thickness and are local in nature with good infiltration characteristics and are composed of course sand, sandy loam and loams.

### 3.4 GEOMORPHOLOGY OF THE STUDY AREA

Geomorphology refers to the scientific study of the Earth's surface physical processes and the resulting landforms shaped by these processes. These geomorphological processes involve the interaction between natural forces and the Earth's surface, leading to various landforms produced by both external and internal forces. It serves as a valuable tool for identifying groundwater resources by examining diverse landforms and drainage systems. Typically, KHSB showcases a dendritic drainage pattern, characteristic of solid rock formations. Contributions by Strahler (1952, 1957), Melton (1957), Leopold and Miller (1956), and others have significantly advanced the field of geomorphology. The geological structure profoundly influences the formation of landforms and is evident within them (Thornbury, 1968). Landforms exhibit differing physical and chemical attributes, often influenced by the structural features of the rocks they develop upon, shaped by various geomorphic processes. A thorough geomorphological study of the region was conducted to identify suitable sites for groundwater recharge. The preparation of a geomorphological map relied on specific characteristics such as tone, texture, size, shape, and associated features extracted from remotely sensed data. Geomorphology significantly contributes to evaluating groundwater availability, highlighting its paramount importance. Different geomorphic surfaces were delineated using KSRSAC data, emphasizing their relevance in assessing and understanding groundwater dynamics.

Delineating and mapping various landform and drainage factors that may directly affect the occurrence and movement of groundwater are part of geomorphological investigations. Understanding areas of groundwater recharge and their potential for groundwater development is greatly helped by the mapping activities (Singhal and Gupta, 1999). Geomorphology is a key factor involved in controlling the groundwater regime of any terrain (Singh 1999; Ravi Shankar and Mohan 2005; Mondal et al. 2007; Gurugnanam et al. 2008; Raghu and Reddy 2011). Geomorphic units such as structural hills, pediment, pediplain, inselberg, plateau, mesa, and butte have been found in the study area. Although these areas often have weak groundwater sources, structural (hills) features enable infiltration of water and include springs/seepages at the lower part. Pediment is an erosional geomorphic feature developed by the process of weathering, having a thin veneer of deposition mostly restricted to the periphery of high relief outcrops. In this unit, the potential for groundwater is typically limited due to the extensive rocky surface. However, in regions characterized by granitic terrains featuring multiple fractures or joints, there exists an opportunity for infiltration and storage of groundwater. Consequently, the groundwater potential varies from moderate to poor based on factors such as the depth of weathered material and the presence or absence of secondary structures.

Inselbergs, solitary residual hillocks formed from weathering and erosion processes, are primarily located within granitic terrains. Acting as runoff zones, these geomorphic features generally exhibit minimal groundwater potential. Pediplains, on the other hand, result from weathering in arid and semi-arid environments, signifying the final stage of cyclic erosion (King 1950, Sparks 1960). Through the interpretation of soil maps and field surveys, pediplains have been identified across various lithological units, characterized by varying layers of accumulated material on shallow to moderately weathered rocks. Shallow weathered pediplains develop gradually through the process of pedimentation at low gradients, covered by shallow weathered material and sparse vegetation. Groundwater potential in such areas ranges from poor (almost arid conditions) to moderate (gentle slopes adjacent to stream courses/tanks). In contrast, moderately weathered pediplains typically manifest as nearly flat terrains with gentle slopes, often occurring along major drainage courses or intermittent streams that dictate the course of valleys. Consequently, the groundwater prospects within this unit are considered moderate to good, contingent upon the thickness of the weathered zone (K. Avinash et al., 2011).

Plateaus in the study area are typical units derived from Deccan traps. These range in highly dissected to moderately dissected to undissected plateaus. Highly dissected are regions where no considerable source of ground water are found as these are restricted to hills and foot-hills where gradient is quite low where as in moderately dissected to undissected plateaus moderate to good aquifer zones can be found (Varade et al., 2017).

Structural Geomorphic units such as Plateaus, Hills and valleys, terraces, benches and geomorphic forms such as mesa, crestline and dissections are separately demarcated. In the denudational regime, plateaus and slopes are delineated based on the underlying rock types. In addition, there is appreciable laterite cover which is part of the weathering regime. Based on hydrological conditions there are several lithological zones. Areas with basalt with or without intertrappean, in which groundwater is restricted to 100 m depth in weathered residuum, fractures and interconnected vesicles whereas the regions with Quartzite, Shale, Slate, Limestone and dolomite, having ground water restricted to 60 m depth in weathered and fracture zones and gneiss, granite and other intrusive with groundwater restricted to 60 m depth in weathered residuum and fracture zones and down to 300 m depth in structurally disturbed areas. The water table ranges from 650m to 700 m above mean sea level. The classification of geomorphological features within the study area is illustrated in figure 3., while area statistics are presented in table 3.4.

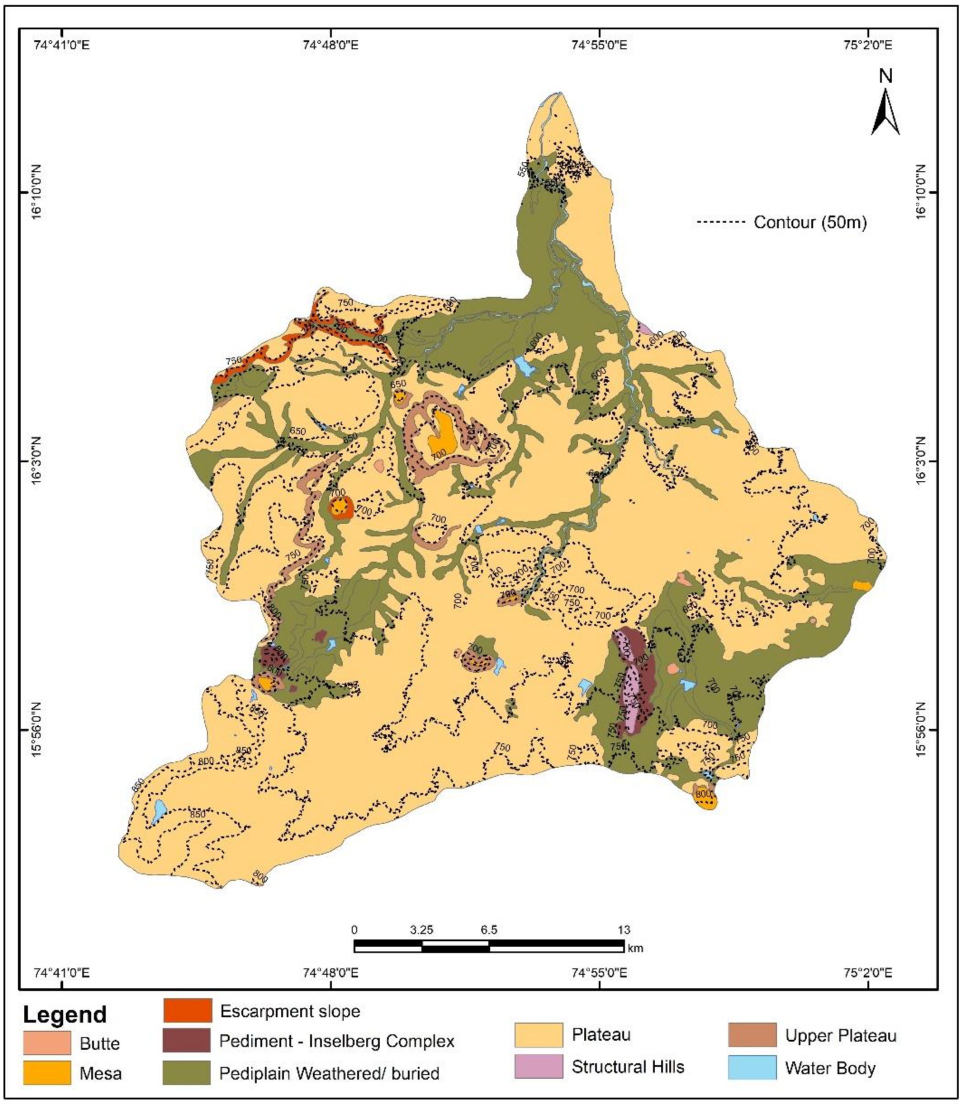



Figure 3.2 Geomorphology along with contours of the study area

Table.3.4 Categories of Geomorphologic features and corresponding area statistics

| **Sl No** | **Geomorphology Classes** | **Area ($Km^2$)** | **Area (%)** |
|---|---|---|---|
| 1 | Structural hills | 2.62 | 0.38 |
| 2 | Plateau | 479.63 | 69.92 |
| 3 | Mesa | 4.52 | 0.66 |
| 4 | Butte. | 0.9 | 0.13 |
| 5 | Upper Plateau | 13.84 | 2.02 |
| 6 | Pediment– inselberg complex | 6.1 | 0.89 |
| 7 | Pediplain weathered /buried | 168.2 | 24.52 |
| 8 | Water Body | 5.4 | 0.79 |
| 9 | Escarpment slope | 4.80 | 0.69 |
| | **Total** | **686** | **100** |

## 3.5 SUMMARY

In the realm of groundwater studies, geology and geomorphology play pivotal roles, shaping the quality, distribution, and movement of groundwater resources. The diverse nature of rock types be it igneous, sedimentary, or metamorphic brings about varying porosity, permeability, and hydraulic conductivity, directly impacting how groundwater flows within the subsurface. Concurrently, geomorphology examines landforms and their influence on groundwater behavior. Moreover, soil diversity stands as another crucial element in groundwater research due to its range of permeability, significantly affecting water flow through different soil types. The amalgamation of insights from geology, geomorphology, and soil types empowers geologists and hydrogeologists to craft accurate models depicting groundwater flow patterns, identify potential sources of contamination, assess areas where groundwater recharge occurs, and efficiently manage water resources. The employment of a multidisciplinary approach proves pivotal in ensuring the sustainable management of groundwater and safeguarding this invaluable natural resource.

# CHAPTER 4

# GROUNDWATER EXPLORATION

## 4.1 INTRODUCTION

Importance of water began when civilizations flourished adjacent to river banks or water bodies as known in the history. In areas like tropical humid regions, water is taken for granted since the availability of water is enormous both on surface as well as groundwater in the subsurface. Since the water is the basic necessity for daily life, thus settlements shift from place to place in search of water especially in arid and semi-arid regions. By minimizing groundwater exploitation, we can preserve the groundwater very effectively. Assessing groundwater potential and its development options involves both qualitative and quantitative understanding of the aquifer systems (Ewusi& Kuma 2014). Targeting the groundwater in hard rock terrains like Deccan basalt, gneissic, quartzite is not always easy. Groundwater in crystalline rocks mainly occurs in shallow weathered zones in narrow limited extent. As fracture zones are mechanically weak and foci for weathering, they can store and transmit more groundwater than intact rocks and form the main aquifers (Magaia et al., 2018). It is essential to carry out the combined studies on the geological, geomorphological and hydrogeological factors for better assessment of groundwater in any given basin or area. For groundwater exploration in any kind of terrain, it is vital to carry out the combination of geophysical and drilling which gives the utmost promising solution by providing the descriptions of the subsurface over large areas at minimal cost and faster (Kosinski& Kelly, 1981). Delineation of weathered and fractured layers has been attempted by Majumdar et al., (2000). Evaluation of depth, thickness and groundwater conditions for shallower aquifer have been done using Schlumberger configuration by Lashkaripour (2003) in Korin basin. Further, efficient use of vertical electric sounding (VES) and profiling methods using Schlumberger and Wenner configurations were done by Al-Amri (1996). The electrical resistivity technique using vertical electrical sounding (VES) approach has been effectively and broadly used for groundwater investigation in the basement terrains (Anudu et al., 2011; Barongo&Palacky, 1991; Olayinka, 1992; Olayinka&Olorunfemi, 1992; Olorunfemi&Fasuyi, 1993; Olorunfemi, &Okhue1991; Omosuyi 2000) since it is easier in describing the important contrast in the geo-electric parameters. In wenner method all four electrodes must be moved to obtain each reading whereas in schlumberger method only two electrodes are moved to obtain multiple readings, hence it can significantly decrease the time required to acquire a sounding. Since all electrodes are shifted for each reading, Wenner method is more susceptible to near-surface, lateral variations in resistivity. These near-surface lateral variations could potentially be misinterpreted in terms of depth variations in resistivity but in schlumberger, this kind of variations in resistivity are reduced as the potential electrodes remain in fixed positions for number of readings. Therefore, schlumberger configuration is followed in the present study for its effective results. Water scarcity is the major problem in KHSB except in rainy seasons, since there is no other source of water availability for irrigation, domestic and industrial purposes. For understanding the hydro-geological condition it is necessary to know the lithological characters and geology of the KHSB. Also to understand the subsurface geology, geophysical techniques are the best known method.

The parameters like longitudinal unit conductance (S), transverse unit resistance (T) (Dar-Zarrouk (D-Z) parameters) offer additional realistic support in order to demarcate the fresh water from the saline water zone (Gupta et al., 2015; Mondal et al., 2013). This investigation is mainly focused on characterizing the aquifers and to find the depth of the aquifer in KHSB. The geo-electrical modelling has been done in order to find lateral extent of aquifer and also to assess the protective capacity of the overburden from the surface contaminants, using D-Z parameters in KHSB of Ghataprabha River basin drained by Ghataprabha River, Belagavi district, Karnataka.

## 4.2 ELECTRICAL RESISTIVITY METHOD

Electrical and electromagnetic techniques are frequently employed in groundwater investigations due to the consistent correlations observed between electrical properties, geological formations, and the fluid they contain. Employing geophysical methods in groundwater investigations has become essential to minimize the risk of drilling unproductive wells and to mitigate the expenses linked with inadequate groundwater production.

Electrical resistivity is the measure of resistance that a unit cube of a substance presents across its opposing faces. For a conductor with a length 'l', a cross-sectional area 's', and resistivity ρ, the expression for resistance (R) is given by,

$$R=\rho\frac{l}{s}. \qquad (4.1)$$

The unit of resistivity is expressed as Ohm.m ($\Omega m$). The conductivity ($\sigma$ ) is defined as the reciprocal of resistivity i.e.$1/\rho$.

The electrical resistivity technique stands out as the oldest and most established geophysical method for selecting well and borehole sites. This approach encompasses two primary survey methods: profiling and depth sounding. In contrast to depth sounding, the resistivity profiling method is a relatively gradual process used to identify lateral variations.

Profiling serves the purpose of outlining the lateral changes in resistivity, typically providing some insights into vertical variations as well. During field measurements, the obtained apparent resistivity generally depends on the depth of investigation and the configuration of electrodes utilized. Apparent resistivity $\rho a$ is determined by the application of Ohm's law ,which takes into account the geometry of electrodes by using a geometric factor "K". The apparent resistivity $\rho a$ can be calculated by using the formula

$$\rho a = K\frac{\Delta V}{I} \qquad (4.2)$$

Where,

I=current applied into the ground

V=potential difference measured across the potential electrodes, and

K=geometrical factor, depending on the distances between the potential and current electrodes.

Apparent resistivity, which is estimated from surface measurements, is a function of depth of investigation used. When the ground is homogeneous, the apparent resistivity is equal to true resistivity.

A review of the literature indicates that vertical electrical depth sounding (VES) remains widely utilized across many regions globally. This method primarily generates a one-dimensional resistivity profile beneath the midpoint of the survey area. VES is specifically designed to assess vertical variations in resistivity. The technique involves incrementally expanding the electrode spacing during measurements while maintaining the central point of the entire array. As the electrode spacing (AB/2) increases, the current penetrates to deeper levels. Consequently, plotting the apparent resistivity (ρa) against electrode spacing provides a visual representation of resistivity variation with depth. Additionally, qualitative interpretation of data from VES surveys enables the determination of resistivity and thickness values for subsurface layers.

The primary advantage offered by the electrical resistivity method lies in its potential for quantitative interpretation aided by computer software (MacDonald et al., 2005). This enables precise determinations of subsurface layer depth, thickness, and resistivity from the obtained data. Additionally, this method boasts non-destructive characteristics. However, a few limitations hinder the efficacy of the electrical resistivity method. It proves unsuitable for use in industrial zones emitting electrical noise radiation, as such interference diminishes the accuracy of resistivity meter measurements. Structures like power lines and grounded metallic elements such as metal fences, pipelines, and railroad tracks can adversely affect the accuracy of resistivity measurements. The setback of this survey is that, it requires more number of laborers to plug the electrodes for each measurement due to which resistivity survey is usually restricted to relatively small-scale investigations. Therefore, this technique is not commonly used for reconnaissance exploration (Kearey, & Brooks, 2002).

### 4.2.1Field Procedure

#### *4.2.1.1 Introduction*

Irrespective of the electrode configuration utilized, resistivity surveys employ only two procedures. The selection between these methods depends on whether the focus is on investigating resistivity variation concerning depth or lateral extent. The first method is Electrical Profiling, while the second is Vertical Electrical Sounding (VES), the latter being the method used in the current investigation. In VES, the portion of total current penetrating the depths changes in accordance with the separation between the current electrodes. To derive depth-wise insights into lithological variations and structures, it becomes essential to arrange the electrodes in a manner that enables the alteration of current electrode separation, facilitating the acquisition of relevant depth-related information.

#### *4.2.1.2 Electrode separation*

Figure 4.2 and 4.3 shows the field arrangement of the Schlumberger configuration where, the direction of potential lines and the movements of current into the ground are shown. Four electrodes are arranged collinearly, the potential electrodes M and N on the inside while current electrodes A and B are on the outside. To alter the depth range being investigated, the distance AB is gradually extended symmetrically while maintaining the position of MN. However, when the ratio AB/MN exceeds a certain threshold, the potential drop across MN becomes too minute to be measured accurately. Thus, it becomes necessary to increase the MN distance. For obtaining a resistivity value with reasonable accuracy, it's recommended to maintain MN at approximately MN~AB/5. This ensures a resistivity value accurate to within a few percentage points. Additionally, readings at AB/2 should be taken at various MN/2 values to identify the existence of lateral heterogeneity. In resistivity measurements the current used is usually DC from a battery. Schlumberger configuration is a co-linear electrode arrangement as shown in figure.4.3.

The conventional resistivity survey equipment consists of a power source, a current and potential measuring device along with a self-potential cancelling facility, cable and electrodes. In Schlumberger configuration, compared to current electrode separation, the distance between the two consecutive electrodes (placed in between the current electrodes) is very small (less than 1/5). The interpretation is based on the assumption that this distance is infinitesimal. The geometrical factor for Schlumberger arrangement is expressed as:

$$K=2\pi\,(L^2 - l^2)/2l \tag{4.3}$$

Where, l and L are half potential electrode and half-current electrode separations respectively. It is quite customary to call the half potential electrode separation by MN/2 and half-current electrode separation (L) by AB/2., M, N and A, B being the potential and current electrodes respectively as shown in figure.4.2. The potential electrodes are closely spaced while the current electrodes are widely separated.

#### ***4.2.1.3 Materials and methods***

In this investigation, the IGIS resistivity meter MODEL SSR-MPL1 was utilized, employing four electrodes positioned in a linear configuration. These electrodes were carefully inserted into the ground at appropriate intervals to maintain a considerable disparity between the separation of current electrodes and the spacing of potential electrodes, aligning with the Schlumberger array depicted in figure 4.3 (Oseji et al., 2005).

This array was selected to ensure enhanced depth penetration, achieved by geometrically increasing the separation between current electrodes for each successive reading concerning the potential electrode spacing. This configuration was chosen not only to optimize deep probing but also for practical considerations such as the logistical constraints of limited manpower and efficient time management. Notably, the potential electrodes were seldom relocated (Okolie et al., 2007). The apparent resistivity($\rho a$) values obtained from the SSR-MPL1 were plotted against the corresponding half current electrode spacing in log-log graph, from which qualitative analysis of the subsurface was made (Ako and Osundo 1986). Quantitative method is followed for better interpretation by using IPI2WIN software to interpret the subsurface layer parameters. The IGIS resistivity meter MODEL SSR-MPL1 and its accessories were used in the present study. The accessories include stainless steel electrode, cables, hammers and tape. The main idea of conducting DC electrical resistivity survey is to understand the subsurface resistivity distribution in the ground and later to understand porosity, lithology and degree of water saturation.

The basic parameter obtained in the DC electrical survey is resistivity, which is different from the resistance(R) which is measured in ohms. Ohm's law defines V = I/R or R = V/I, where V = voltage in volts and I = current in amps (William J. Johnson, et al., 2003). Ability of a material to conduct electricity is known as conductivity which is the inverse of resistivity. Suppose R is the resistance of a block of conductive material having length (l) and cross sectional area (A), then resistivity can be expressed as $\rho = RA/L$. Resistivity is usually measured by passing the current through two electrodes on either side of the point of investigation and measuring the potential across two receiving electrodes. Apparent resistivity ($\rho a$) is calculated from the current (I) and voltage (V) values, which is given in the formula. $\rho a = kV/I$. where k is the geometric factor, which is subjected to the arrangement of the four electrodes. In the current field study, the Vertical Electrical Soundings (VES) using schlumberger configuration were made at 40 locations distributed throughout the Kanavi Halla Sub Basin (KHSB), having different lithology and soil type in the area (Figure 4.1).

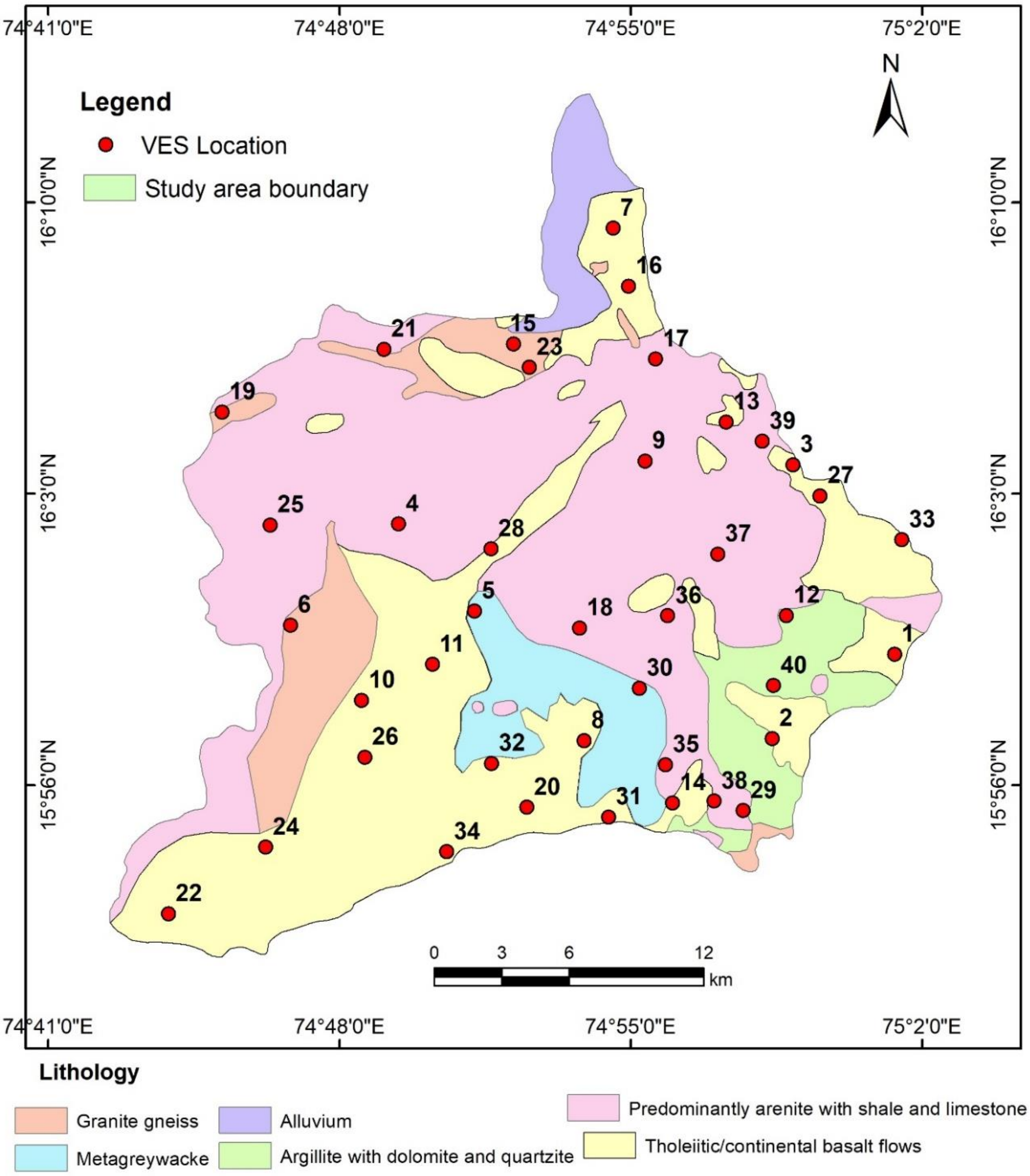



Figure 4.1 VES locations on geological map of KHSB

VES approach is followed since it is the most reliable method for groundwater exploration in most geological occurrences (Ojelabi et al 2001, Ramakrishnan, Vaidyanadhan 2010, Sharma, P.V 1997). The VES have been conducted spreading throughout the study area and locations are shown on geological map (Figure 4.1). The instrument used for these surveys is the Integrated Geo Instruments & Services Pvt. Ltd (IGIS) Resistivity meter. The Vertical Electrical Sounding (VES) has become most popular by its efficiency in groundwater investigation due to its simplicity (Kana et al., 2015). In determining the resistivity variation with depth, the Schlumberger sounding is well known (Sharma 2005). The arrangement and set up of the Schlumberger configuration is shown below where the continuous red lines represent current flow and dashed lines are electrical potential (voltage) in figure 4.2 and 4.3.

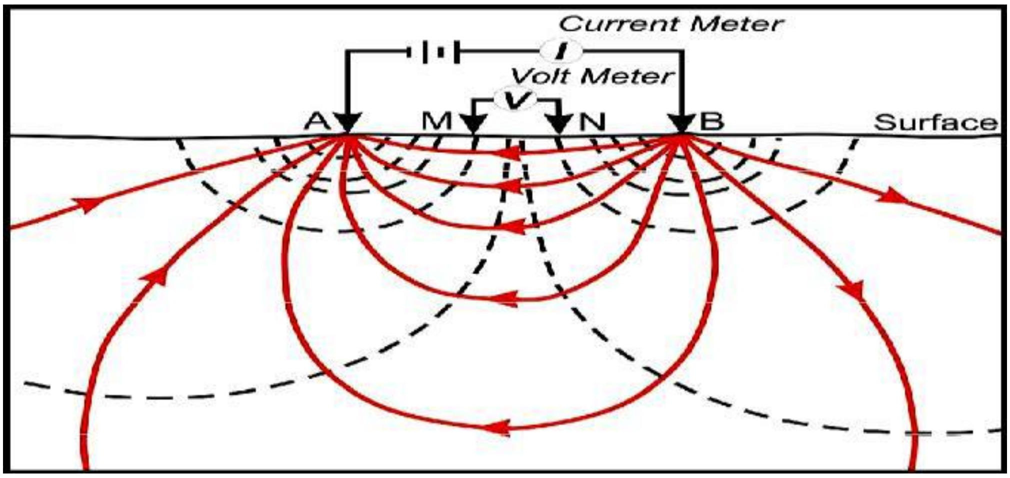



Figure 4.2 Schematic illustration of the resistivity method (James A. Clark 2011)

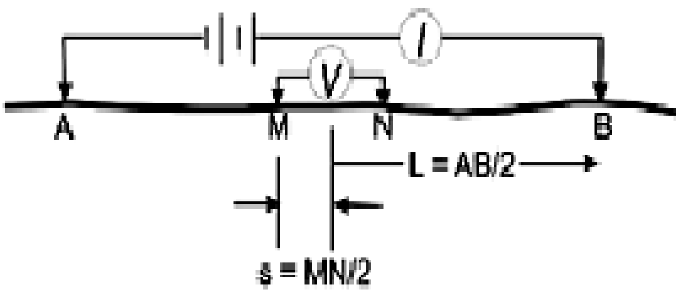



Figure 4.3: Schematic illustration of Schlumberger array (James A. Clark 2011)

The maximum current electrode spacing of AB/2=420m is maintained. The Schlumberger configuration comprises four (4) collinear probes. The inward two probes are potential (receiver) electrodes and the outward two probes are current source electrodes (source electrodes). In fact, the present investigation is 1-D pattern for data acquisition. With a small separation, the potential electrodes are arranged at the center of electrode array, typically less than or equal to one fifth of the spacing between the current electrodes (MN/2<= 1/5AB/2). The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage become too small to measure. With larger separation of electrodes, deeper subsurface investigations can be made.

#### *4.2.1.4 Methods of interpretation*

There are two types of interpretation methods to analyze the resistivity data. One such method is qualitative method which is based on curve matching technique and the other one is computerized interpretation method. The literature review highlights mainly on the usage of quantitative method in most of the cases. However, the qualitative method is also used in many cases along with quantitative method.

The analysis of subsurface resistivity distribution through the observation of the field curve's shape is commonly referred to as qualitative interpretation. Conversely, interpreting the data by plotting apparent resistivity values (determined from equation 4.2) against half-electrode spacing values (as shown in Figure 4.4) on a logarithmic scale is known as the quantitative method. Field curves are generated, and the count of inflections on the curve is employed to estimate layer resistivity and thicknesses. Figure 4.4 presents typical curve patterns for different layers in electrical resistivity data interpretation: Q-type (descending), H-type (Hummel type with a minimum), A-type (ascending), and K-type (displaced anisotropic). The K-type curve ascends to a maximum level and then descends, suggesting that the middle layer possesses higher resistivity compared to the top and bottom layers. In contrast, the H-type curve exhibits the opposite trend, descending to a minimum and then rising again due to an intermediate layer with superior conductivity than the top and bottom layers. The A-type curve may display some variations, but generally, as the electrode spacing increases, the apparent resistivity steadily rises, indicating an increase in true resistivity with depth across layers. Conversely, the Q-type curve shows a continuous decrease in apparent resistivity with depth

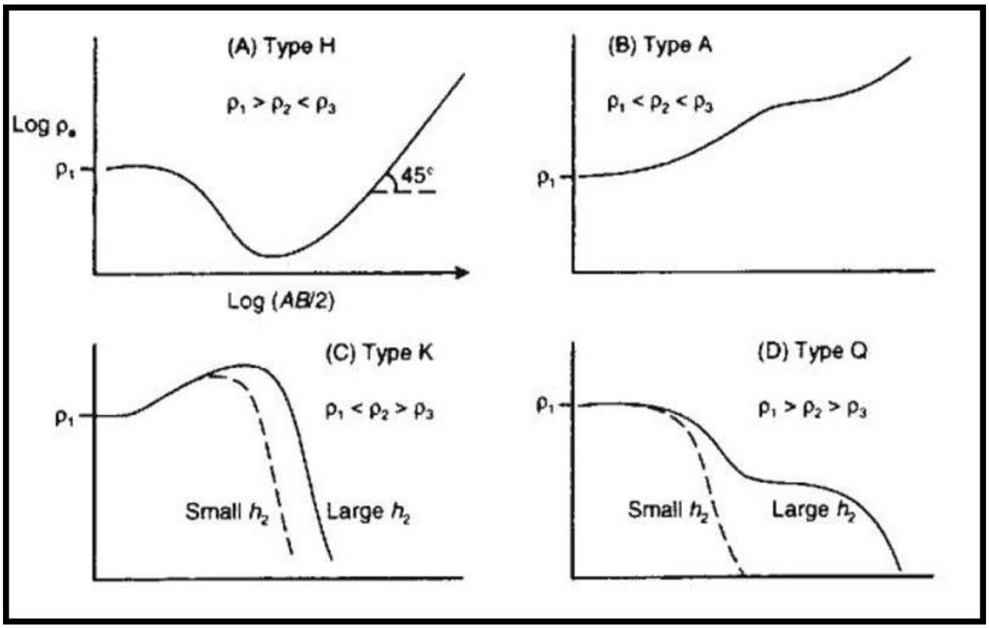



Figure 4.4. Representation of basic VES curves of the qualitative method. (source: http://www.ukm.edu.my/rahim/Resistivity%20lecture.htm).

The H-type Curve indicates a scenario where a low resistivity layer exists between two high resistivity layers, representing a typical three-layer case ($\rho1 > \rho2 < \rho3$).

The A-type Curve demonstrates a pattern where the resistivity of the layers exhibits continuous increments ($\rho1 < \rho2 < \rho3$).

The K-type Curve illustrates a high resistivity layer situated between two low resistivity layers ($\rho1 < \rho2 > \rho3$).

The Q-type Curve depicts a trend where resistivity continuously decreases with depth ($\rho1 > \rho2 > \rho3$).

In the quantitative method, curve matching involves the utilization of master curves. This method entails plotting apparent resistivity against electrode spacing to create a curve, which is then interpreted by aligning the field curve with the master curve. Consequently, subsurface layers are categorized into H, K, A, and Q type curves based on their distinctive shapes (Bharti, 2016). The resistivity distribution of various subsurface layers is delineated as follows: H-type exhibits $\rho\ 1 > \rho\ 2 < \rho\ 3$; K-type demonstrates $\rho\ 1 < \rho\ 2 > \rho\ 3$; A-type showcases $\rho\ 1 < \rho\ 2 < \rho\ 3$; while Q-type reflects $\rho\ 1 > \rho\ 2 > \rho\ 3$. Based on the above data and nature of the curve further curves can be classified as 4,5,6 layers as KA, HQ, AA, HKH, HKHK, -type, and so on. Among this H and combination with H curves are considered as a water potential curves.

The qualitative data can be easily got by plotting the apparent resistivity values versus electrode spacing while for quantitative interpretation there are many softwares. Among them IPI2WIN (Figure-4.5 and 4.6) is the most extensively used software for partial curve matching technique.

#### *4.2.1.5 Interpretation of the Sounding Curves*

To obtain apparent resistivity (ρa) values, the geometric factor K was first calculated for all the electrode spacing using the formula K=π (L2/2b - b/2) for Schlumberger array with MN/2=S and AB/2=L and then the values obtained were then multiplied with the resistance values. Then apparent resistivity (ρa) values were plotted against the current electrode spacing (AB/2) on a log-log graph to obtain VES curves. Using computer software IPI2WIN, VES sounding curves have been (Figure 4.5 and 4.6) interpreted for layer parameters (Abdullahi et al., 2015)

The ground data acquired were interpreted using IPI2WIN Resistivity Sounding Interpretation Software (1990-2008).2-D geo-electric section has been produced by IPI2WIN from 1-D data in various trends considered randomly.

#### *4.2.1.6 Assessment of Dar-Zarrouk (D-Z) parameters*

In the current study, the Dar-Zarrouk (D-Z) parameters, viz. transverse unit resistance (T), longitudinal unit conductance (S), longitudinal resistivity (ρl), transverse resistivity (ρt), electrical anisotropy and Root mean square resistivity (ρm) have been considered to evaluate the VES data (Singh and Singh 1970; Henriet 1976; Salem 1999; Ayolabi et al., 2010).

For a unit cross-sectional area, longitudinal unit conductance(S) is the conductance which is parallel to the face, which plays a significant part in resistivity soundings. Transverse unit resistance (T) is normal to the face. These are enough to calculate the distribution of surface potential and thus an electrical resistivity graph (Henriet 1976; Mondal et al., 2013).

If the section comprises of n-geo-electrical layers with thickness h1, h2, …, hn and resistivity ρ1, ρ2, ρ3, …, ρn for a block of unit square area and thickness $H = \sum_{i=1}^{n}$ hi

(Mondal et al., 2013). The S and T are set equal to those for an anisotropic block with a unit square area so that the longitudinal unit resistance,

$$S = \rho 1h1 + \rho 2h2 + \rho 3h3 \ldots\ldots\ldots\ldots\ldots . \rho nhn = \sum_{i=1}^{n} \rho ihi \quad (4.4)$$

Transverse unit conductance,

$$T = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \frac{h3}{\rho 3} \ldots\ldots\ldots\ldots\ldots \frac{hn}{\rho n} = \sum_{i=1}^{n} \frac{hi}{\rho i} \quad (4.5)$$

The transverse resistivity (ρt) to the current flowing at right angles to the layers is specified by:

$$\rho t = \frac{T}{H} \quad (4.6)$$

The longitudinal resistivity (ρl) to the current flowing parallel to the layers is specified by:

$$\rho l = \frac{H}{S} \quad (4.7)$$

Electrical anisotropy (λ) is given by:

$$\lambda = \sqrt{\frac{\rho t}{\rho l}} \quad (4.8)$$

Root mean square resistivity (ρm) is given by

$$\rho m = \sqrt{\rho t \rho l} \quad (4.9)$$

The above factors were used to demarcate the freshwater zones in KHSB and also to determine the aquifer protective capacity. In order to study the aquifer protection studies and to examine the hydrologic properties of the aquifer, the combination of layer resistivity and thickness in D-Z Parameters S and T may be directly used as mentioned by Henriet (1976).

### 4.3 INTERPRETATION OF VES DATA

The ground data from VES was interpreted and evaluated both quantitatively and qualitatively using IPI2WIN software and by using the various subsurface layers and their corresponding thickness (Table 4.1).

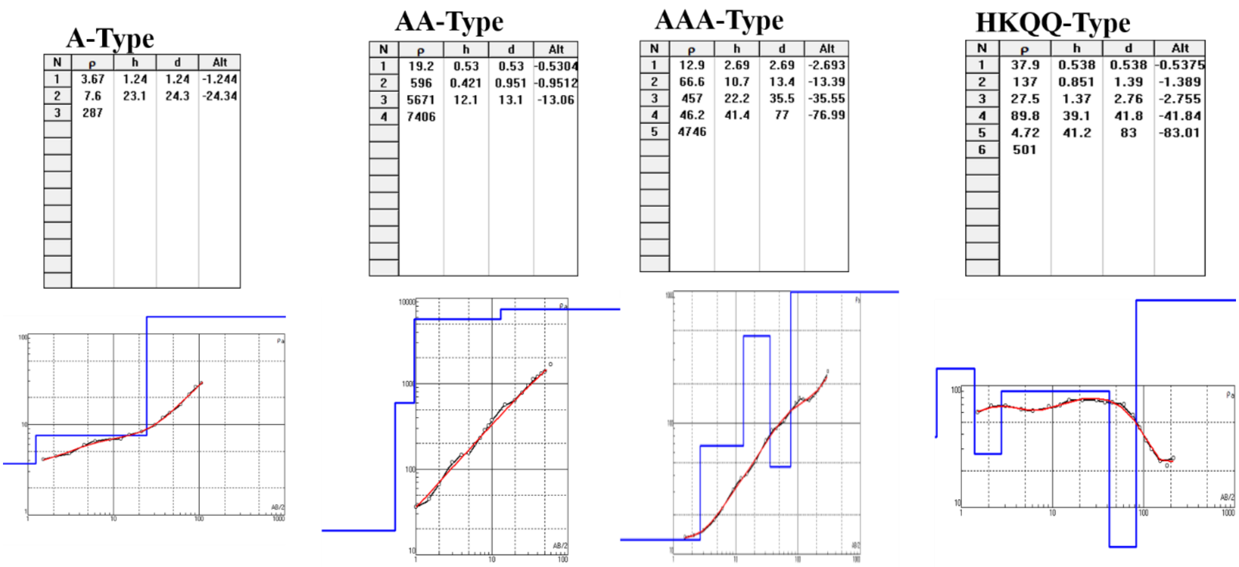
Table 4.1 Layer parameters

| | | | **Layer Resistivity Ω-m** | | | | | | **Thickness (m)** | | | | | **Depth** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VES NO** | **Geology** | **Curve type** | **ρ1** | **ρ2** | **ρ3** | **ρ4** | **ρ5** | **ρ6** | **h1 'm'** | **h2 'm'** | **h3 'm'** | **h4 'm'** | **h5 'm'** | **(m)** |
| 1 | Basalt | HAA | 5.04 | 1.98 | 222 | 12.6 | 8635 | | 2.28 | 2.74 | 7.12 | 22.2 | | 34.4 |
| 2 | Quartzite | KQH | 1530 | 2861 | 272 | 161 | 8635 | | 2.28 | 1.99 | 7.87 | 23.7 | | 35.8 |
| 3 | Basalt | H | 71.2 | 5.26 | 1515 | | | | 4.2 | 11.5 | | | | 15.7 |
| 4 | Arenite | AKQH | 41.5 | 164 | 30.3 | 132 | 5.27 | 208 | 1.22 | 3.47 | 4.23 | 14.6 | 30 | 53.8 |
| 5 | Basalt | KH | 67.4 | 141 | 11.6 | 862 | | | 4.03 | 23.4 | 148 | | | 176 |
| 6 | Granite gneiss | H | 116 | 4.36 | 335 | | | | 1.16 | 17.8 | | | | 19 |
| 7 | Basalt | A | 2.15 | 10.2 | 893 | | | | 5.09 | 27.5 | | | | 32.6 |
| 8 | Basalt | HQH | 354 | 13.9 | 140 | 5.04 | 4658 | | 0.5 | 0.1 | 8.39 | 12.8 | | 21.8 |
| 9 | Arenite | HA | 106 | 7.27 | 26.4 | 130 | | | 1.91 | 1.8 | 14.3 | | | 18 |
| 10 | Basalt | K | 53 | 103 | 44.2 | | | | 3.72 | 36.4 | | | | 40.1 |
| 11 | Basalt | AK | 35.2 | 203 | 13 | 1829 | | | 13.6 | 22.2 | 140 | | | 176 |
| 12 | Quartzite | A | 4.39 | 135 | 299 | | | | 3.22 | 5.06 | | | | 8.28 |
| 13 | Basalt/Quartzite | H | 526 | 170 | 547 | | | | 6.36 | 76.4 | | | | 82.8 |
| 14 | Metagreywacke | A | 9.06 | 33.9 | 4359 | | | | 2.67 | 21.9 | | | | 24.6 |
| 15 | Granite Gneiss | KH | 6.9 | 104 | 1.61 | 4042 | | | 0.76 | 1.08 | 4.72 | | | 6.56 |
| 16 | Basalt | H | 5.89 | 2.44 | 133 | | | | 2.84 | 5.65 | | | | 8.49 |
| 17 | Arenite | KH | 45.1 | 79.4 | 22.9 | 6373 | | | 1.75 | 14.2 | 18.5 | | | 34.4 |
| 18 | Arenite | A | 53.8 | 83 | 965 | | | | 0.762 | 12.2 | | | | 13 |
| 19 | Granite Gneiss | A | 35.3 | 107 | 5217 | | | | 1.56 | 15.4 | | | | 17 |
| 20 | Basalt | H | 22.6 | 3.83 | 135 | | | | 2.16 | 7.11 | | | | 9.27 |
| 21 | Granite Gneiss | H | 984 | 183 | 707 | | | | 2.31 | 6.47 | | | | 8.77 |
| 22 | Basalt | AAK | 336 | 1037 | 7678 | 125 | 6602 | | 1.64 | 9.72 | 30.6 | 36.5 | | 78.5 |
| 23 | Gneiss | A | 3.67 | 7.60 | 287 | | | | 1.24 | 23.1 | | | | 24.3 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Basalt | HAK | 5974 | 1.30 | 15.9 | 449 | 19 | | 0.24 | 0.36 | 4.05 | 9.93 | | 14.6 |
| 25 | Sst/Qtz | AA | 19.2 | 596 | 5671 | 7406 | | | 0.53 | 0.42 | 12.1 | | | 13.1 |
| 26 | Basalt | HK | 77.5 | 24.1 | 520 | 38.2 | | | 1.99 | 1.5 | 2.82 | | | 6.31 |
| 27 | Basalt/sidnal slab | KH | 13.4 | 978 | 5.7 | 1629 | | | 0.80 | 1.4 | 13.3 | | | 15.5 |
| 28 | Basalt | HKQQ | 37.9 | 137 | 27.5 | 89.8 | 4.72 | 501 | 0.54 | 0.85 | 1.37 | 39.1 | 41.2 | 83 |
| 29 | Shale | HA | 5.65 | 3.07 | 30.9 | 6965 | | | 0.95 | 6.31 | 61.5 | | | 68.7 |
| 30 | Schist | H | 515 | 116 | 1881 | | | | 0.76 | 15.9 | | | | 16.7 |
| 31 | Basalt | HK | 154 | 26.55 | 122.6 | 38.7 | | | 0.46 | 0.4 | 18.81 | | | 19.67 |
| 32 | Basalt | HKH | 71.05 | 30.66 | 55.68 | 15 | 900 | | 0.43 | 4.79 | 19.81 | 28.2 | | 53.24 |
| 33 | Basalt | KH | 2.15 | 754 | 3.76 | 532 | | | 0.49 | 0.56 | 4.78 | | | 5.83 |
| 34 | Basalt | AAK | 9.03 | 12.10 | 232 | 23.8 | 4830 | | 0.81 | 6.24 | 26.3 | 97.3 | | 131 |
| 35 | Sst/Qtzt | HA | 5995 | 350 | 128 | 1824 | | | 0.33 | 5.83 | 16.5 | | | 22.6 |
| 36 | Sst/Qtzt | AAA | 12.9 | 66.6 | 457 | 46.2 | 4746 | | 2.69 | 10.7 | 22.2 | 41.4 | | 77 |
| 37 | Sst/Qtzt | KH | 2.97 | 786 | 6.87 | 2119 | | | 0.71 | 0.55 | 6.14 | | | 7.41 |
| 38 | Sst/Qtzt | H | 15.7 | 5.39 | 1622 | | | | 2.12 | 17.7 | | | | 19.8 |
| 39 | Sst | KH | 13.1 | 856 | 7.64 | 503 | | | 0.84 | 1.63 | 14 | | | 16.4 |
| 40 | Sst | KH | 124 | 1401 | 17.4 | 117 | | | 0.30 | 0.75 | 0.99 | | | 2.04 |

Totally forty vertical electrical soundings (VES) were conducted in the study area. Sounding curves are obtained by plotting the apparent resistivity values against distance between the electrodes on a log-log graph. Representative VES curves are presented and the types of curve are also presented along with their data (Figure 4.5, 4.6 and Table 4.1). The interpreted data from IPI2WIN software showing minimum RMS error of 1% and maximum RMS error of 11% between calculated and measured resistivity. In the figure 4.5 and 4.6, red line shows field curve obtained from the resistivity value and is matched with the existing black line which is a standard curve, as this method is partially curve matching technique. Blue lines represent each layer resistivity with respect to Y axis. From the obtained VES curves interpretation, subsurface layers of the study area are classified as different types (Selvam, & Sivasubramanian, 2012).

Totally 17 type of curves, based on the layer parameters, are obtained in the present investigation The curve types obtained are AAK-type (VES 22, 34), HA-type (VES 9, 29, 35), A- type (VES 7,12,14, 18,19 and 23), KH-type (VES 5,15, 17, 27, 33, 37, 39 and 40), KQH-type (VES 2), H-type (VES 3,6,13,16,20, 21, 30 and 38), AK-type (VES 11), K-type (VES 10), HQH-type (VES 8), HAA-type (VES 1), AKQH-type (VES 4), AA-type (VES 25), HK-type (VES 26 and 31), HAK-type (VES 24), AAA-type (VES 36), HKH-type (VES 32), and HKQQ-type (VES 28).




A-Type

| N | ρ | h | d | Alt |
|---|---|---|---|---|
| 1 | 3.67 | 1.24 | 1.24 | -1.244 |
| 2 | 7.6 | 23.1 | 24.3 | -24.34 |
| 3 | 287 | | | |

AA-Type

| N | ρ | h | d | Alt |
|---|---|---|---|---|
| 1 | 19.2 | 0.53 | 0.53 | -0.5304 |
| 2 | 596 | 0.421 | 0.951 | -0.9512 |
| 3 | 5671 | 12.1 | 13.1 | -13.06 |
| 4 | 7406 | | | |

AAA-Type

| N | ρ | h | d | Alt |
|---|---|---|---|---|
| 1 | 12.9 | 2.69 | 2.69 | -2.693 |
| 2 | 66.6 | 10.7 | 13.4 | -13.39 |
| 3 | 457 | 22.2 | 35.5 | -35.55 |
| 4 | 46.2 | 41.4 | 77 | -76.99 |
| 5 | 4746 | | | |

HKQQ-Type

| N | ρ | h | d | Alt |
|---|---|---|---|---|
| 1 | 37.9 | 0.538 | 0.538 | -0.5375 |
| 2 | 137 | 0.851 | 1.39 | -1.389 |
| 3 | 27.5 | 1.37 | 2.76 | -2.755 |
| 4 | 89.8 | 39.1 | 41.8 | -41.84 |
| 5 | 4.72 | 41.2 | 83 | -83.01 |
| 6 | 501 | | | |

Figure 4.5 Representation of VES curve

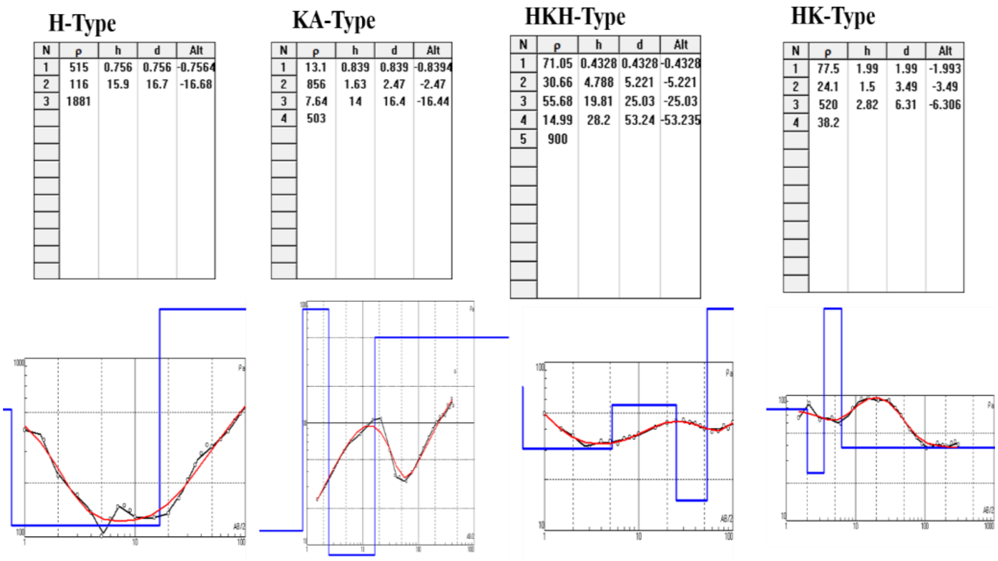



Figure 4.6. Representation of VES curve

The interpretation of the sounding curves obtained from the VES on different litho units may vary since the strata varies from place to place. Expected subsurface layers in Basaltic terrain is soil layer, followed by moderately hard formation, weathered jointed formation, homogeneous jointed formation, highly weathered loose and collapsible jointed formation, hard formation may be jointed and finally hard massive formation devoid of joint and fractures. Here the weathered could be jointed zone to hard formation may be treated as aquifer zones based on the depth of each layer. In quartzite area expected subsurface strata could be soil weathered formation and followed by hard formation, hard jointed formation, hard massive formation, jointed formation, hard formation, homogeneous jointed formation, highly weathered loose and collapsible jointed formation, further jointed formation and homogeneous formation. Here the formation associated with joints can be considered as aquifer zones. In gneissic terrain the expected strata could be soil and weathered formation followed by moderately weathered formation, hard formation, weathered jointed formation, jointed formation, hard formation, homogeneous jointed formation, hard formation and soft jointed formation, may be collapsible. Here weathered and jointed formation is treated as aquifer zone.

In the present investigation the maximum number of soundings are carried out in the basaltic terrain and sandstone/quartzite and some are in gneissic, shale and schist terrains to understand the variation in the resistivity values and also to know the depth of occurrence of water. Interstitial pore spaces and fractures in vesicular basalts are good storehouses of groundwater. The interpreted layers and their parameters reveal that, in the basaltic terrain, the first layer is the topsoil consisting of black and clayey soil and in few places brownish soil, greyish soil also observed. In the case of quartzite, sandstone and gneissic terrain, the top layer is red soil and brownish soil.

In general, the thickness of the first layer varies from 0.24 to 2 meters and resistivity for the same ranges up to 5995 Ωm. With very small thickness, it is not suitable for groundwater occurrence. The second layer thickness varies from 0.36 to 23 m and resistivity varies up to 1401 Ωm which is generally weathered and fractured zone. This is probably the first aquifer zone at shallow depth with less yield. Third layer thickness is 1 to 61 m and resistivity value goes up to 5671 Ωm. This high value is due to quartzite terrain which is usually jointed formations but in this case joints might be dry. The fourth layer resistivity is up to 7406 Ωm which is quite high resistivity revealing the hard rock formation whose thickness is upto 97m. Succeeding to the this, resistivity varying up to 4830 Ωm which is quite low resistivity and thickness is upto 41m revealing the better aquifer zone since the thickness of the layer is large and possibilities of getting better yield. This is followed by the last layer whose resistivity values is up to 501 Ωm. So, second layer, third layer and fifth layers are feasible and yield might be good. The suggested depth to be drilled for hand pumps is around 60 m and for bore well is 100 to 250m. In the hard rock terrains like basaltic, gneissic, quartzite usually the yield of the bore well is poor. Therefore, air compressor pump may be fitted for effective use of bore wells (Source: DMG reports).

In basaltic, quartzite and gneissic regions, the availability of groundwater is poor in dug wells but water can be extracted from dug cum bore well and bore wells from deeper levels. The poor yield or failures of bore wells in the quartzite, gneissic and basalt regions are because of the dry joints at very shallow depths and existence of massive quartzite, gneissic and basalts free of fissures and fractures at deeper level. Probability of unconfined aquifers are very rare in these kind of regions and we have to look for the confined aquifer which can be located with the help of electrical resistivity survey. Since the availability of water in dug wells is very less especially during summer months, deep bore wells are the viable option to get water in the area throughout the year.

The interpretation of the resistivity data is done based on the available bore well drillings observed during the present investigation. The example of borewell log for Basaltic terrain, Basaltic/Gneissic terrain, Quartzite/Gneissic terrain and Shale terrain is given in the figure 4.7. The observed borewell drillings show various kind of formations in the subsurface. The observations may help to understand the subsurface very easily and to correlate with the resistivity data and for further suggestion to bore well drillings. The blue colour in the bore well log represents the aquifer zone. Based on the thickness and the obtained water during drilling, aquifer zone is classified as I, II, III, IV and V. Contact zone represents the change in the lithological formation in the subsurface.

| Depth | Legend | Type of formation(Basalt-Kanagavi) |
|---|---|---|
| 0'-7' | | Soil with compact Basalt |
| 7'-40' | | Moderately hard basalt |
| 40'-70' | | Weathered jointed Basalt (Aquifer Zone-I) |
| 70'-125' | | Jointed Basalt (Aquifer Zone-II) |
| 125' - 400' | | Highly weathered loose and collapsible jointed Basalt (Aquifer Zone-III) |
| 400'-500' | | Jointed Basalt (Aquifer Zone-IV) |
| 500'-700' | | Hard Basalt with minor joints (Aquifer Zone-V) |
| 700' Onwords | | Hard massive Basalt, devoid of joints and fractures |

| Depth | Legend | Type of formation (Basalt/Gneiss-Kodlivad) |
|---|---|---|
| 0'-20' | | Soil+Weathered Basalt |
| 20'-40' | | Moderately weathered basalt |
| 40'-70' | | Hard Basalt |
| 70'-150' | | Weathered jointed Basalt (Aquifer Zone-I) |
| 150' - 200' | | Jointed Basalt (Aquifer Zone-II) |
| 200'-350' | | Hard Basalt |
| 350'-700' | | Jointed Basalt (Aquifer Zone-III) |
| 700'-800' | | Hard Basalt |
| 800'-1000' | | (Contact Zone) Soft jointed Gneiss |

| Depth | Legend | Type of formation (Quartzite/gneiss- Suthgatti) |
|---|---|---|
| 0'-10' | | Soil+Weathered Quartzite |
| 10'-30' | | Hard Quartzite |
| 30'-70' | | Hard jointed quartzite (Aquifer Zone-I) |
| 70'-100' | | Hard Massive quartzite |
| 100' - 200' | | Jointed Quartzite (Aquifer Zone-II) |
| 200'-300' | | (Contact Zone) Hard Gneiss |
| 300'-350' | | Jointed Gneiss(Aquifer Zone-III) |
| 350'-600' | | Highly weathered loose and collapsible jointed Gneiss (Aquifer Zone-IV) |
| 600'-1000' | | Jointed Gneiss (Aquifer Zone-V) |

| Depth | Legend | Type of formation (Shale- Yaragatti) |
|---|---|---|
| 0'-30' | | Soil formation |
| 30'-125' | | Moderately weathered Shale |
| 125'-200' | | Weathered jointed Shale (Aquifer Zone-I) |
| 200'- 400' | | Jointed Shale (Aquifer Zone-II) |
| 400'-600' | | Hard Shale with joints (Aquifer Zone-III) |
| 600' Onwords | | Hard Shale devoid of joints and fractures |

Figure 4.7 Observed bore well log/bore well drillings for different terrains

## 4.4 INTERPRETATION OF DAR-ZARROUK (D-Z) PARAMETERS

A total of 40 VES were carried out using Schlumberger configuration in the KHSB (Figure 23). The various D-Z parameters were considered, viz., longitudinal unit conductance (S), transverse unit resistance (T), longitudinal resistivity ($\rho_l$), electrical anisotropy ($\lambda$) and root mean square resistivity ($\rho_m$) to find the potential zones of groundwater, to delineate the fresh groundwater zones and to examine the saline water intrusion. The data of calculated D-Z parameters is presented in table 4.2.

Table 4.2 Dark-Zarrouk (D-Z) Parameters values

| VES NO. | S | T | Pl | Pt | λ | Pm |
|---|---|---|---|---|---|---|
| 1 | 3.63 | 1877.3 | 9.5 | 54.6 | 2.40 | 22.7 |
| 2 | 0.18 | 15138.1 | 200.8 | 422.9 | 1.45 | 291.4 |
| 3 | 2.25 | 359.5 | 7.0 | 22.9 | 1.81 | 12.7 |
| 4 | 5.99 | 2833.2 | 9.0 | 52.7 | 2.42 | 21.7 |
| 5 | 12.98 | 5287.8 | 13.6 | 30.0 | 1.49 | 20.2 |
| 6 | 4.09 | 212.2 | 4.6 | 11.2 | 1.55 | 7.2 |
| 7 | 5.06 | 291.4 | 6.4 | 8.9 | 1.18 | 7.6 |
| 8 | 2.61 | 1417.5 | 8.4 | 65.0 | 2.79 | 23.3 |
| 9 | 0.81 | 593.1 | 22.3 | 32.9 | 1.22 | 27.1 |
| 10 | 0.42 | 3946.4 | 94.7 | 98.4 | 1.02 | 96.5 |
| 11 | 11.26 | 6805.3 | 15.6 | 38.7 | 1.57 | 24.6 |
| 12 | 0.77 | 697.2 | 10.7 | 84.2 | 2.80 | 30.1 |
| 13 | 0.46 | 16333.4 | 179.4 | 197.3 | 1.05 | 188.1 |
| 14 | 0.94 | 766.6 | 26.2 | 31.2 | 1.09 | 28.5 |
| 15 | 3.05 | 125.2 | 2.1 | 19.1 | 2.98 | 6.4 |
| 16 | 2.80 | 30.5 | 3.0 | 3.6 | 1.09 | 3.3 |
| 17 | 1.03 | 1630.1 | 33.5 | 47.4 | 1.19 | 39.9 |
| 18 | 0.16 | 1053.6 | 80.7 | 81.0 | 1.00 | 80.9 |
| 19 | 0.19 | 1702.9 | 90.4 | 100.2 | 1.05 | 95.1 |
| 20 | 1.95 | 76.0 | 4.7 | 8.2 | 1.31 | 6.2 |
| 21 | 0.04 | 3457.1 | 232.6 | 394.2 | 1.30 | 302.8 |
| 22 | 0.31 | 250140.0 | 253.0 | 3186.5 | 3.55 | 897.9 |
| 23 | 3.38 | 180.1 | 7.2 | 7.4 | 1.01 | 7.3 |
| 24 | 0.55 | 5933.3 | 26.5 | 406.4 | 3.92 | 103.7 |
| 25 | 0.03 | 68880.2 | 430.3 | 5258.0 | 3.50 | 1504.2 |
| 26 | 0.09 | 1656.8 | 67.6 | 262.6 | 1.97 | 133.2 |
| 27 | 2.39 | 1455.7 | 6.5 | 93.9 | 3.81 | 24.7 |
| 28 | 9.23 | 3685.8 | 9.0 | 44.4 | 2.22 | 20.0 |
| 29 | 4.21 | 1925.1 | 16.3 | 28.0 | 1.31 | 21.4 |
| 30 | 0.14 | 2233.7 | 120.5 | 133.8 | 1.05 | 127.0 |
| 31 | 0.17 | 2387.9 | 114.7 | 121.4 | 1.03 | 118.0 |
| 32 | 2.40 | 1703.3 | 22.2 | 32.0 | 1.20 | 26.6 |
| 33 | 1.50 | 442.0 | 3.9 | 75.8 | 4.42 | 17.2 |
| 34 | 4.81 | 8500.1 | 27.3 | 64.9 | 1.54 | 42.1 |
| 35 | 0.15 | 6100.9 | 155.2 | 270.0 | 1.32 | 204.7 |
| 36 | 1.31 | 12805.4 | 58.6 | 166.3 | 1.68 | 98.7 |
| 37 | 1.13 | 476.6 | 6.5 | 64.3 | 3.14 | 20.5 |
| 38 | 3.42 | 128.7 | 5.8 | 6.5 | 1.06 | 6.1 |
| 39 | 1.90 | 1513.2 | 8.6 | 92.3 | 3.27 | 28.2 |
| 40 | 0.06 | 1103.5 | 34.1 | 541.0 | 3.99 | 135.7 |

### 4.4.1 Transverse unit resistance (T)

Transverse unit resistance variation is shown in figure 4.8 (a). Table 4.2 reveals that the T value at VES 16 ranges from 30.5 Ω-m$^2$ to maximum value at VES 22 as 250140 Ω-m$^2$. It is observed that the high T values (>700 Ω-m$^2$) were exhibited by VES locations 1, 2, 4, 5, 8, 10, 11, 13, 14, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 39 and 40 in KHSB which indicates the presence of fresh water zone. The increasing trend of the T values depicts high transmissivity of aquifers. In KHSB, the south eastern part is characterized by low T values (<700 Ω-m$^2$).

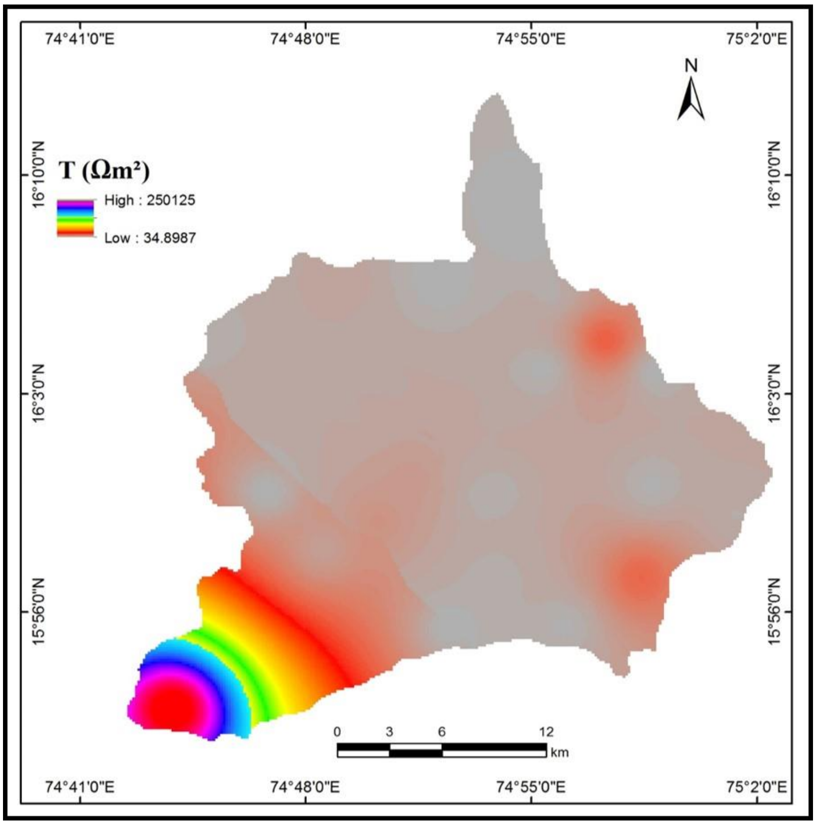



Figure.4.8 (a)Transverse unit resistance (T)

### 4.4.2 Longitudinal unit conductance (S)

The longitudinal conductance varies from 0.04 to 12.98 in KHSB (Figure 4.8(b)). The eastern part along with certain patches towards NW and SE depicted low S values (0.04-1) including VES locations 2, 9, 10, 12, 13, 14, 18, 19, 21, 22, 24, 25, 26, 30, 31, 35 and 40 whereas high S value (>6) was observed at VES stations 5, 11 and 28 in the central part of the study area. Moderate S value (1-6) was observed in rest of the study area, encompassing VES sites, 1, 3, 4, 6, 7, 8, 15, 16, 17, 20, 23, 27, 29, 32, 33, 34, 36, 37, 38 and 39. It can be estimated that the VES locations with lesser to moderate S value (0.04-6) illustrates the freshwater zone. It is indicative that the locations with higher S value also shows higher H value which means S value is proportional to H value. This designates the deeper basements of freshwater zones (Murali and Patangay 2006; Ayolabi et al. 2010). In present investigation, high S values (12.98, 11.26 and 9.23) at VES locations 5, 11 and 28 were obtained and corresponding depth to the lowermost geo-electric layer is about 176 m, 176m and 83 m respectively having a resistivity of 862, 1829 and 501 Ωm respectively, which might be the hard basement and devoid of fractures in KHSB (Table 4.2).

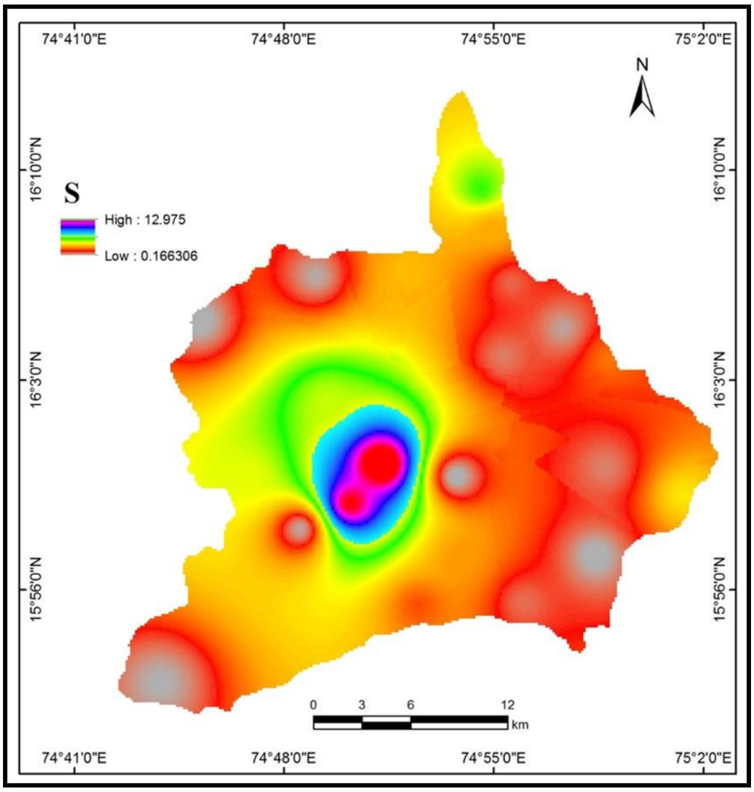



Figure.4.8 (b) Longitudinal unit conductance (S)

Classification suggested by Oladapo and Akintorinwa (2007), Atakpo (2013) shows that the S value is used to categorize the area into six classes as excellent, very good, good, moderate, weak and poor protective capacity zones in decreasing order.

The various classes are considered based on conductance (S) values as excellent, very good, good, moderate, weak and poor protective capacity zones corresponding to S value >10, 5 to 10, 0.7 to 4.9, 0.2 to 0.69, 0.1 to 0.19 and < 0.1. Figure 4.8 (b) shows that about 5 % of the area excellent and 7.5% of the area is shared by the very good protective capacity classes, while 52.5 % showed as good and 10 % of the area is shared by moderate and 15% of the area is shared by weak protective capacity classes, whereas the 10% area is under poor protective capacity class. In general, about 25 % of the area is under weak to poor protective capacity class. Higher value of the protective capacity indicates the presence of significant amount of clay as an overburden impermeable material, thereby protecting the aquifers from the percolation of pollutants contributed by agricultural activities, septic tanks, landfills, if situated near to the survey point. In other words, the lower S value indicates the prone area for percolation of the surface contaminants to the groundwater. As clay content increases the transmissivity will decrease by which it acts as an impermeable layer for contaminants (Gupta et al., 2015).

### 4.4.3 Transverse resistivity (ρt)

Figure 23(c) shows the map for $\rho_t$. This figure is almost similar to the map of T, excluding few patches in NW and SE part (Figure 4.8(c)). It was observed that very low $\rho_t$ values in the northern and southern part at VES 7, 16, 20, 23 and 38 (Table 4.2) probably infers the source of contaminants that might be the waste produced by agricultural and domestic activities. From the resistivity map, it can be concluded that there is no saline water intrusion into this area (Gupta et al., 2015).

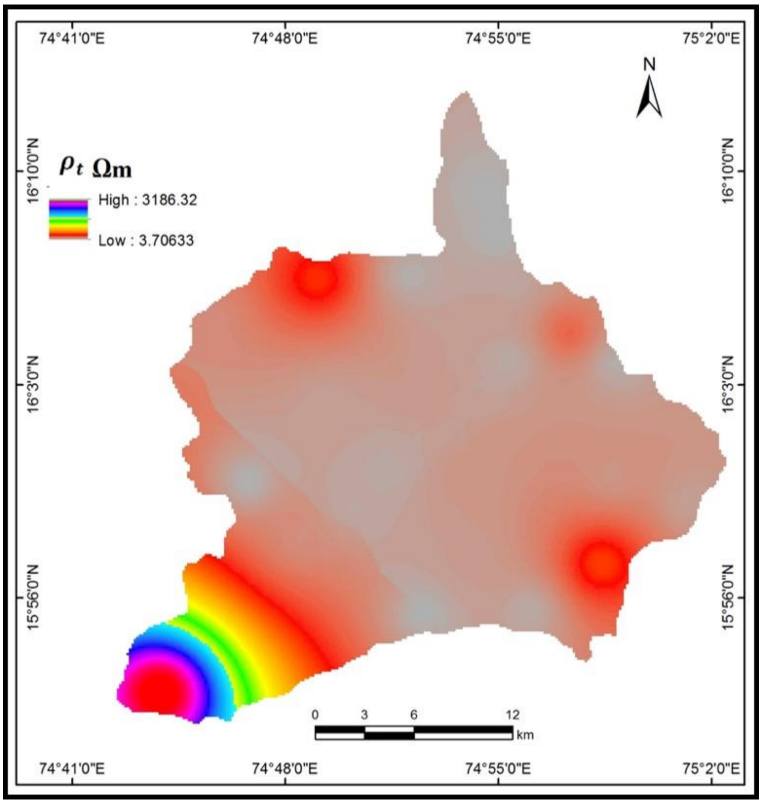



**Figure.4.8 (c)Transverse resistivity ($\rho_t$)**

### 4.4.4 Longitudinal resistivity ($\rho_l$)

The map of longitudinal resistivity shows that the entire KHSB have $\rho_l$ value ranging from 2.1 to 430.3 Ω-m (Figure 4.8(d)). Pockets of south-western, north-western, north-eastern and south-eastern parts showed higher values which are more than 179.4 Ω-m shown by VES 2, 13, 21, 22 and 25 (Table 4.2) and rest of all the area is showing < 155.2 Ω-m. The central part of KHSB showed the $\rho_t$ values ranging from 9-120.5 Ω-m. Generally, the $\rho_l$ values are less than the $\rho_t$ values, except where the medium is even (Flathe 1955), which is witnessed in the current study too. This strongly depicts that the current flow and average hydraulic conduction along the lithology margin are more than those normal to the lithology margin (Ayolabi et al. 2010; Gupta et al., 2015).

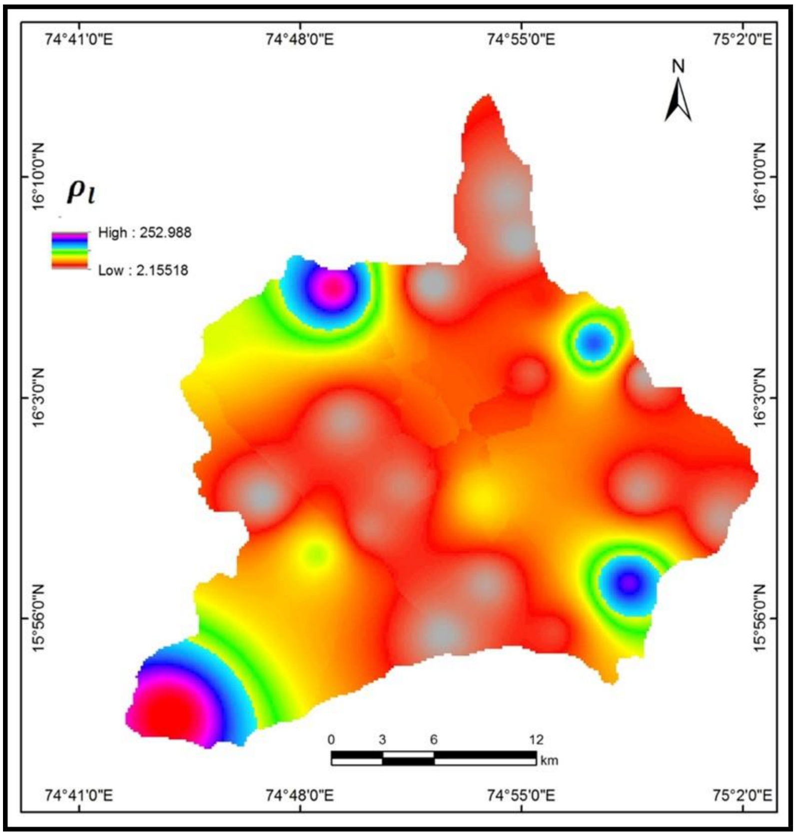



Figure.4.8 (d) Longitudinal resistivity ($\rho_t$)

**4.4.5 Electrical anisotropy(λ)**

The distribution of electrical anisotropy is illustrated in figure 4.8 (e). The values of λ ranged from 1.00 (VES 18) to 4.42 (VES 33) with a mean of 1.97 in KHSB and its spatial distribution is shown (Figure 4.8 (e)). As the λ value is high, it shows that the existent rocks are having high hardness and are compact, which indicates that they are associated with low porosity and permeability (Keller and Frischknecht, 1966). In general, the area with λ value <1 and up to 1.5 will reflect as good potential zone for groundwater (Singh and Singh, 1970). In this study, about 50% of the entire stretch of the study area, λ values are varying between 1.02 to 1.5 and rest of KHSB is showing value >1.5 (VES 1, 3, 4, 6, 8, 11, 12, 15, 22, 24, 25, 26, 27, 28, 33, 34, 36, 37, 39 and 40), implying the hard rock terrain where the groundwater occurrence might be absent or poor potential zones for groundwater occurrence (Table 4.2). Lesser values of λ corresponded to high aquifer potential zones (Singh and Singh, 1970).

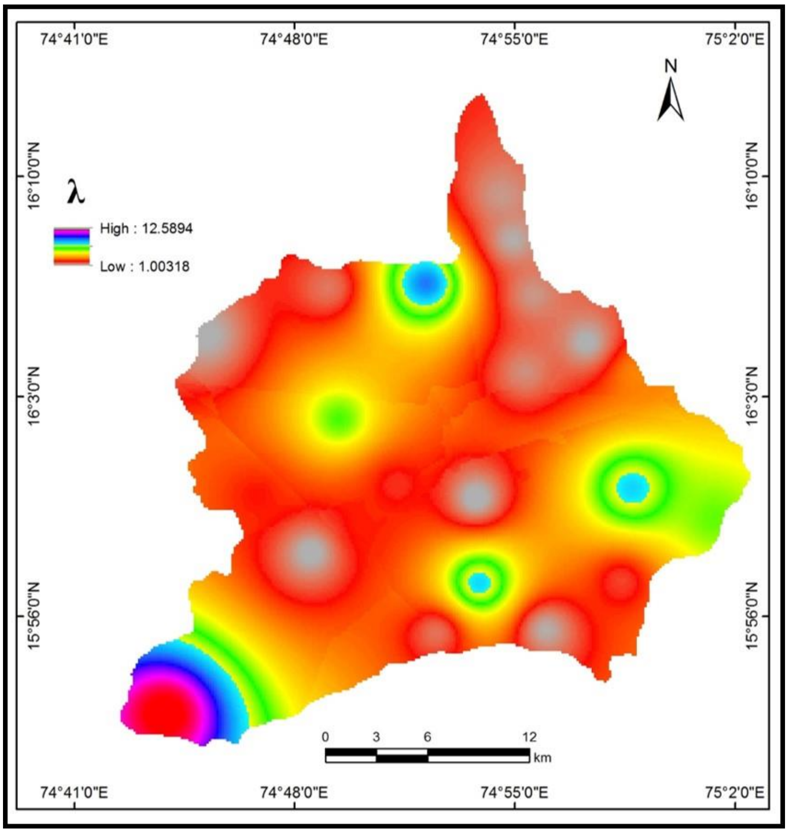



Figure.4.8 (e) Electrical Anisotropy (λ)

#### 4.4.6 Root mean square resistivity ($\rho_m$)

The $\rho_m$ also called as effective resistivity, ranges between 3.3 (VES 16) and 1504.2 Ω-m (VES 25) as shown in table 4.2. When there is difference in the values of all $\rho_t$, $\rho_l$ and $\rho_m$, then the change in resistivity is reliant on the path of groundwater movement and the impact of lithological variation (Khalil 2009). In the present investigation, we have observed the different values of all three resistivity's, hence, it reveals that heterogeneous anisotropic lithology is present in this region.

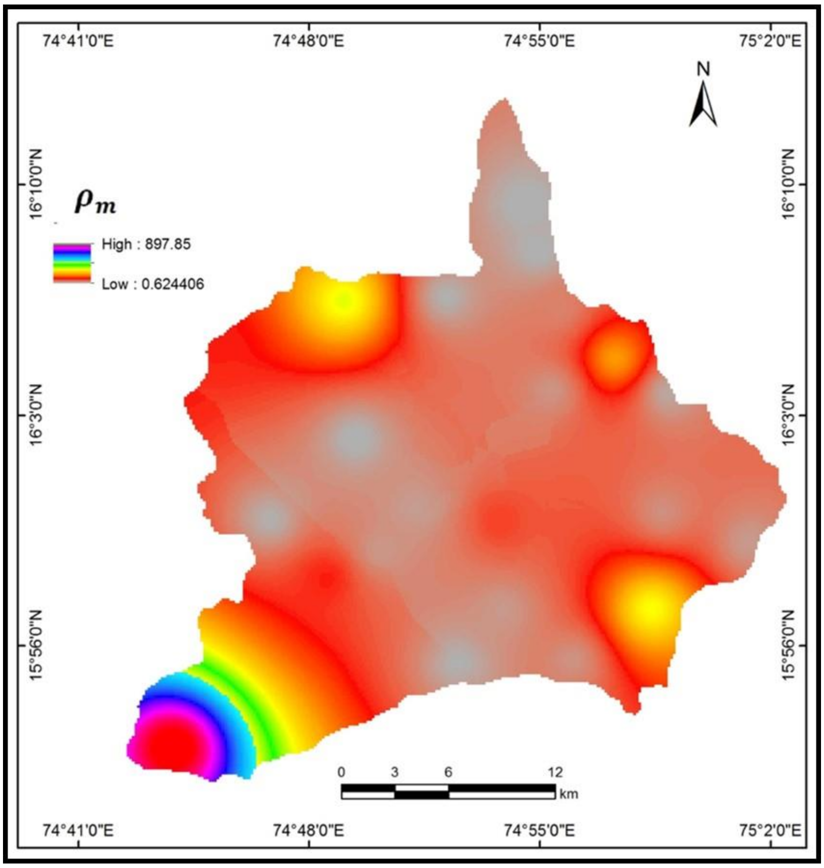



Figure.4.8 (f) Root mean square resistivity ($\rho_m$)

### 4.5 GEO-ELECTRICAL MODELLING

From 1-D data obtained by IPI2WIN software, 2-D geo-electric section has been prepared over five selected directions in order to know the geometry of the aquifer formed in and around KHSB (Figure 4.9). The directions are considered as Profile AB, Profile CD, Profile EF, Profile GH, Profile IJ, Profile KL, Profile MN and Profile XY for its description (Figure 4.10(a-e)). The longitudinal geo-electrical model is exhibited in figures 4.10 (a-e). All these sections show the cross sections in a particular directions and it will be beneficial for locating bore wells (Vasantrao et al., 2017).

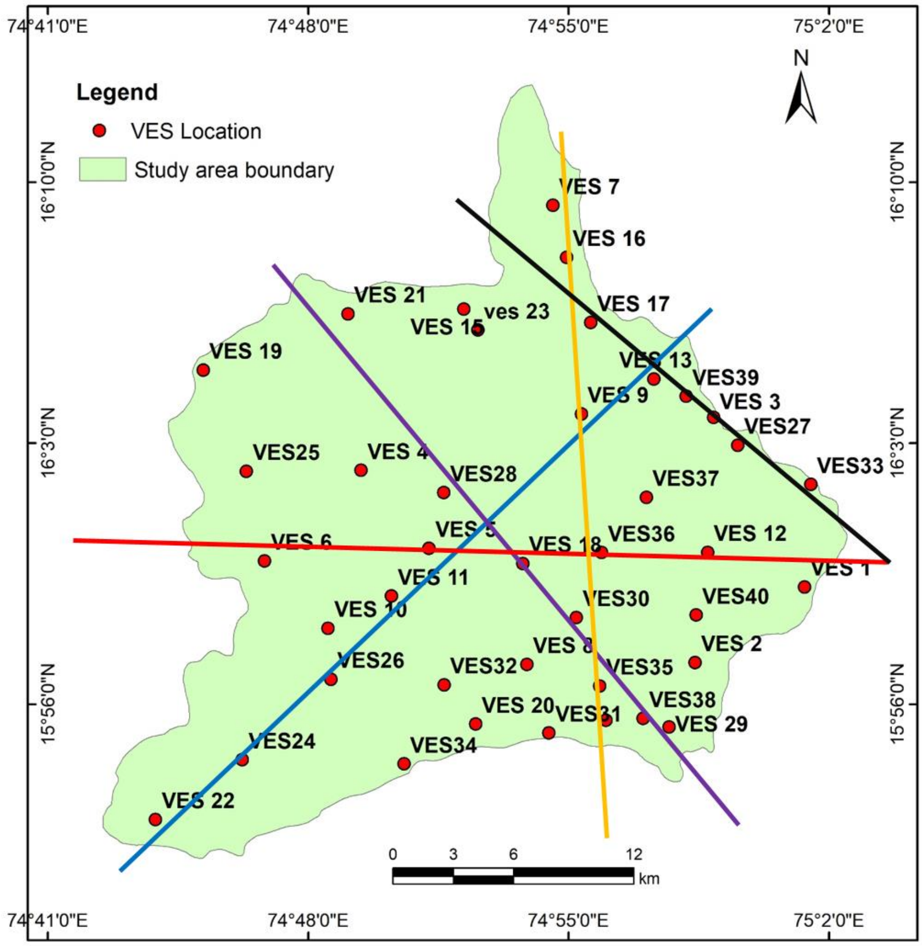



Figure. 4.9 VES location map along with geo-electric sections

### 4.5.1 Profile AB

Figure 4.10(a) shows the profile AB trending in SW-NE direction, including VES points 22, 24, 26,11,9 and 13. VES 24 indicates that upto 300 meter is saturated with water and it extends beneath VES 26 up to 200m and further extends beneath VES 11 and 9 upto 70 m. VES 22 and 13 are characterized by the resistivity range of above 250 Ωm, towards SW and NE direction. The aquifer zones might be at deeper level or might be absent due to hard rock devoid of joints and fractures. Beneath VES 24, 26, 11(Basalt) and 9(Arenite), the subsurface is almost similar and well connected by the aquifer zones. In this trend all VES locations are in basaltic terrain excluding VES 9 which has arenite but beneath VES 22 and 13, it is found that the resistivity is high and might be the contact zone of basalt/quartzite since the nearby drilling shows the quartzite material.

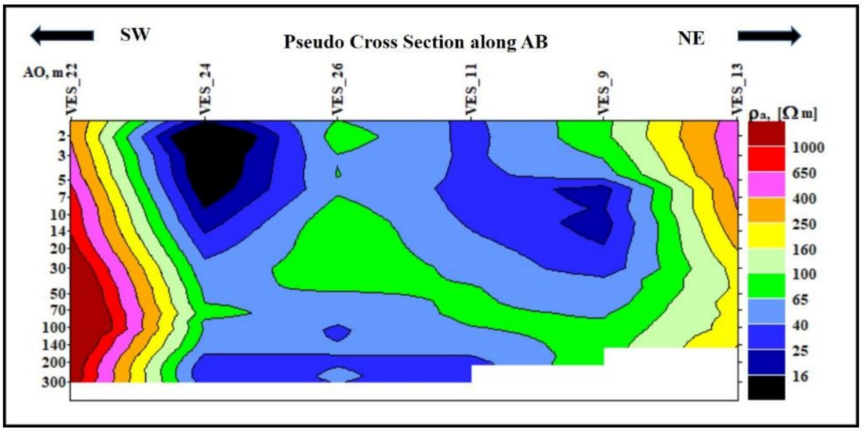



Figure.4.10(a). Longitudinal geo-electrical model along AB trend

**4.5.2 Profile CD**

The Profile along W to E, encompasses VES 6, 5, 18, 36 and 12. Beneath VES 12 top layer shows extreme low resistivity which indicates that top layer is well saturated (figure 4.10(b)). Beneath VES 5 and 18, excluding top 1m layer, the layer resistivity is moderate to high value (65 Ωm to 250 Ωm). Cross section of VES 6 shows that aquifer zone is at shallower depth from 3m to 80m. the VES 36 shows it has connection with the VES 12 with low resistivity range from top to bottom of the layer. Cross-section MN clearly represents the subsurface layers with different resistivity ranges that are well connected at different depths.

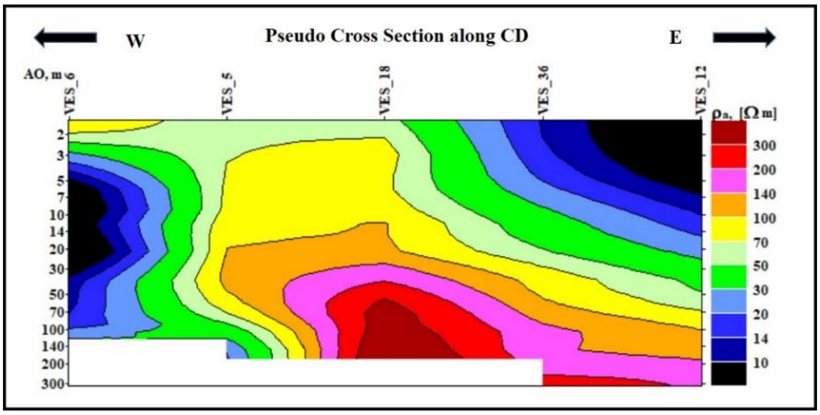



Figure.4.10(b). Longitudinal geo-electrical model along CD trend

### 4.5.3 Profile EF

EF profile trending in SE to NW encompasses VES stations 29, 38, 35, 30,18 and 28. It clearly depicts that the layer resistivity goes on increasing towards central part of SE and NW trend since it exhibits high resistivity (Figure 4.10 (c)). The aquifer zones were observed at shallower depth towards SE direction. Beneath VES 35 and 30 it showed high resistivity range in the deeper layers since it is located in the schist and quartzite terrain. The VES 18 showed top layer of 3 m depth with low resistivity range and further resistivity increased beyond 3m depth indicating that the hard and compact rock in the subsurface devoid of weathered zone. Towards NW direction the depth of the water saturated zone goes on increasing which portrays the availability of good potential zone for groundwater exploration. The aquifer zones were well connected beneath VES 35,30 and 18. Extreme low resistivity value (<20 Ωm) was observed beneath VES 29 and 38. Which might be weathered and collapsible zone. In such instances, casings may be inserted for bore wells. Central part of this trend depicts high resistivity zone and might be devoid of fractures and joints.

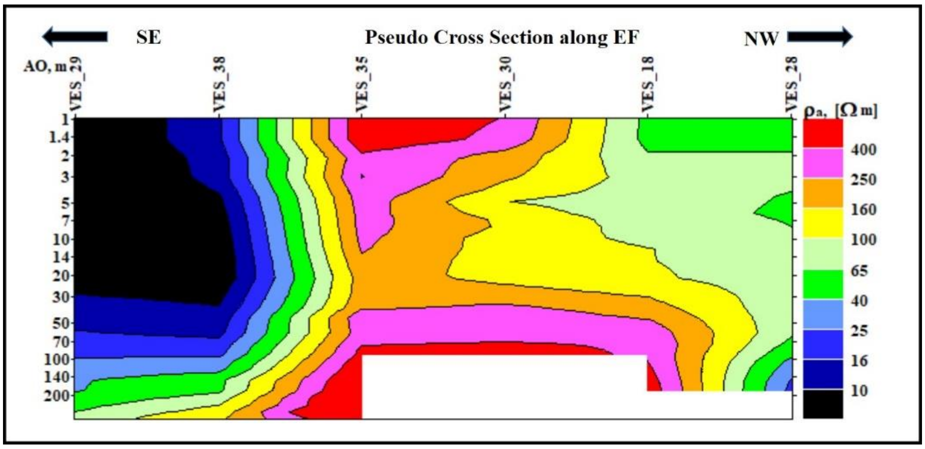



Figure.4.10 (c). Longitudinal geo-electrical model along EF trend

### 4.5.4 Profile GH

The cross section along NNW to SSE consists of VES 17,13,39,3,27 and 33 (Figure 4.10(d)). Excluding VES 13 remaining VES are well connected by aquifer zones with various depths. Whereas beneath VES 13 is the top layer exhibiting high resistivity range of above 237 Ωm which is located on Quartzite terrain. The top layer exhibits high resistivity value and further down other layers show low resistivity. Beneath VES 17,13, 39,3, 27 and 33, top layer up to 7 m exhibits low resistivity of around 56 Ωm and even in the deeper level the resistivity of low range is connected through beneath VES 17,39,27 and 33 which is mainly due to the presence of litho units of porous and permeable nature in this trend. Low resistivity trend goes towards SSE direction.

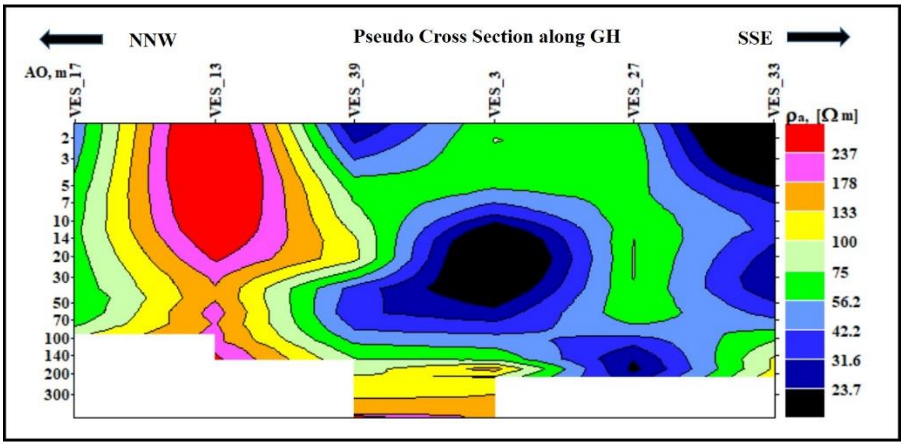



Figure.4.10 (d). Longitudinal geo-electrical model along GH trend

### 4.5.5 Profile IJ

The profile of VES stations 7, 16, 17 and 12 is trending in N -S (Figure 4.10 (e)). There was a continuous increase in the resistivity as depth increased beneath the VES 7 and 16 that may be due to water saturation at shallower depth, but in the deeper levels, high resistivity value shows that there might be chances of failure of bore wells. Cross section of VES 17 shows moderate range of resistivity from the surface to deeper levels. Thus, it can be observed that this trend may indicate hard rock terrain beyond shallower depth and there are rare chances of availability of good aquifers. Beneath 30 and 35 it showed high resistivity range at shallower depth and in the deeper layers since it is located in the schist and quartzite terrain. But in the depth of 10 m and 70 m there is quite low resistivity as compared to shallower depth so there might be the chance of presence of fractures and joints, in the deeper layers. VES 9, 18 and 31 are showing similar variations in the resistivity values so might be well connected in the subsurface.

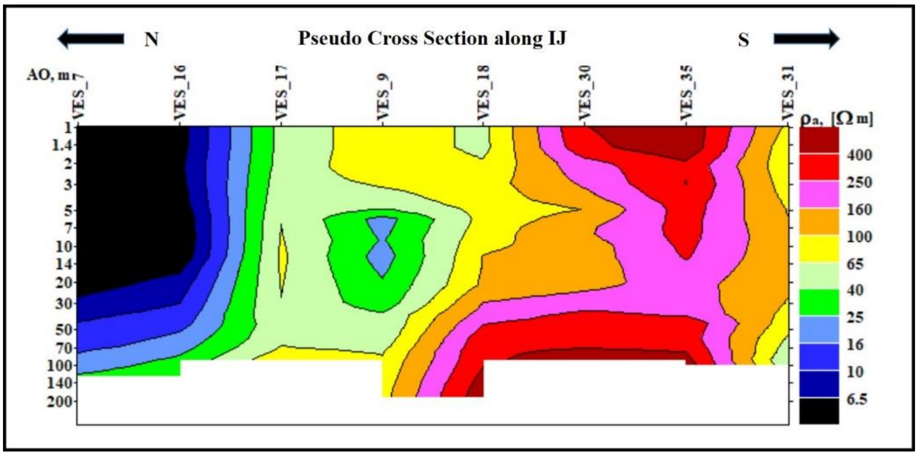



Figure.4.10 (e). Longitudinal geo-electrical model along IJ trend

## 4.6 SUMMARY

It is safe to conclude that VES survey is one of the potential methods to describe the subsurface layers for groundwater investigation and to plan groundwater developmental strategies. Major part of KHSB is underlain by Deccan basalt and limestone. Hence dug wells are the feasible structures in such cases. The current study shows the relation among the hydrogeological, geomorphic and geophysical parameters of groundwater. The outcomes of the resistivity survey conducted in the KHSB shows that out of 40 VES, only 16 VES have been considered as good potential sites, and 14 VES fair to good, whereas the remaining are showing poor potential. Good potential regions identified are VES No. 2,4,5, 6, 8,13,15, 17, 27, 28, 31, 32, 33, 37, 39 and 40. From the interpreted data, 42.5% of the study area is dominated by curve associated with A type curve indicating hard rock terrain. This work highlights the success of electrical resistivity technique in demarcating weathered, jointed and fractured zones which helps in identification of potential groundwater zones.

In the present study the weathered, jointed formation may be interpreted as water bearing zone. 2-D geo-electric section has been drawn using IPI2WIN over five selected trends to understand the geometry of the aquifer formed. The investigation was meant to characterize the aquifer in KHSB along with the risk assessment for contaminants through seepage in terms of protective capacity with the help of Dar-Zarrouk (D-Z) parameters such as longitudinal unit conductance (S), longitudinal resitivity (ρl), transverse unit resistance (T), transverse resistivity (ρt), Electrical anisotropy(λ) and root mean square resistivity (ρm). These were evaluated to know the aquifer conditions in order to demarcate the freshwater bearing zones. South eastern part of KHSB might be contaminated and 22.5% of the area is weak to poor capacity protective zone for contaminants. The work adequately highlights the practical use of geophysical techniques, combination of geo-electrical modelling, D-Z parameters, borehole log in the groundwater resource assessment process. This technique is highly recommended for areas with similar geological setup.

The electrical resistivity method presents a cost-effective and valuable solution for addressing challenges in groundwater exploration, offering insights into aquifer dimensions. This study concludes that electrical resistivity methods excel in identifying fractured zones, aiding in the delineation of groundwater zones. As a result, it is recommended that geophysical methods, particularly the electrical resistivity method employing the Schlumberger configuration in conjunction with geological approaches, become an integral component of groundwater exploration programs. This integration assists in resolving intricate geohydrological issues associated with groundwater occurrence and resource development. The utility of this method in hydrogeological investigations encompasses various aspects: determination of aquifer parameters such as depth, thickness, porosity, hydraulic conductivity, transmissivity, specific yield, and identification of interfaces between saline and fresh water, as well as groundwater contamination. However, when employing the resistivity method, limitations may arise in the presence of ground heterogeneity and anisotropy. Over the past decade, there has been a substantial increase in the utilization of geophysics for groundwater resource mapping. The Vertical Electrical Sounding (VES) method utilizing the Schlumberger arrangement has proven highly reliable for groundwater studies, offering effectiveness in both shallow and deep groundwater investigations.

# CHAPTER 5

# GROUNDWATER QUALITY

## 5.1 INTRODUCTION

Groundwater is one of the natural resources available other than surface water which is of prime importance for the growth and development of mankind. The development of any nation depends on it as sectors such as agriculture, industries, domestic and energy production depends on it. Therefore, availability of groundwater is very important to meet the above requirements. Further, in the present scenario, importance is being given to its sustainable development and conservation such that it meets the needs of present and future generation.

Groundwater is part of Hydrological Cycle, which reaches the subsurface by infiltration through soil and is stored in fractures and joints of permeable geological formations. The numbers and arrangement of interconnected voids in the subsurface determines the quality of water that can be stored with respect to space and time. Apart from quantity, quality of water also plays an important role in its suitability for different purpose such domestic and agriculture. The quality of water is (determined) influenced by the geology and chemistry of water. Different materials are added to the water as it percolates down through soils and as it interacts with geologic media. These materials are minerals which depending upon their solubility and the chemical equilibrium prevailing in the aqueous solution influences its quality (Saunders, 1976). Therefore, both quality and quantity is very important aspect in water quality studies of any basin. Furthermore, with the ever increasing population and increased development have resulted in over exploration and pollution of groundwater resources. Hence, the present chapter deals with groundwater suitability for drinking purpose and agricultural purpose and the various approaches like geochemistry, multivariate statistical study and water quality index studies of Kanvi Halla Sub-Basin.

## 5.2 MATERIALS AND METHODOLOGY

### 5.2.1 Groundwater quality analysis

The groundwater composition is likely to vary from one place to another place, along with the depth of the wells. To understand the quality of groundwater of Kanavihalla Sub-basin, representative groundwater samples were collected. The samples have been collected in a systematic manner by dividing the study area, into a number of grids of 4x4 $km^2$, to cover the entire stretch of the KHSB (Figure 5.1). In total, 45 number of water samples were collected during pre-monsoon (April/2018) and 41 number of water samples were collected during post-monsoon (December/2018). Before going to the field visits pre-studies were done to understand the study area and surrounding areas with respect to its feasibility, geology and field conditions with the help of topographical maps, satellite images and available literatures. During the field visits, samples were collected in polyethylene bottles of 2 litres capacity. The bottles were pre-rinsed and cleaned in the laboratory using dil. HCl and distil water before taking it to field. In the field, the bottles were further washed using representative samples and then water sample collected. Borewells fitted with hand pumps (HP) have been pumped atleast 20-25 strokes to discard the water that is stored in it, in order to reduce the effect of iron pipes; for borewells (BW) the water is pumped for at least 5-10 minutes, in order to avoid errors in the results. Water samples have been collected based on the availability of the borewells and hand pumps and they represent the area uniformly throughout the study area. The collected water samples were concealed air tight to abstain from any contamination and taken to laboratory for analyses at Department of Civil Engineering, NITK. The collected groundwater samples have been examined in the research laboratory of Dept. of Civil Engineering, N.I.T.K. Surathkal, to check the quality with respect to various physico-chemical parameters. Parameters such as temperature (T in $^0$C), hydrogen ion concentration (pH), and Electrical Conductivity (EC) are measured in the field itself using handheld portable instruments. The other parameters, such as Total Dissolved Solids (TDS), sodium (Na), potassium (K), Total Hardness (TH), calcium (Ca), magnesium (Mg) and other major cations and anions are analyzed in the NITK laboratory following standard operating procedures as prescribed by American Public Health Association (APHA, 1998), A.W.W.A. (2012) and approaches for water pollution studies by Trivedy and Goel (1984). The groundwater samples for physiochemical study are placed in a refrigerator at $4^0$ C after being transferred to the laboratory for immediate analysis. The ions such as $Ca^{2+}$, $Mg^{2+}$, $HCO_3$, $CO_3^{2-}$, and $Cl^-$ are tested by titration methods. For measurement of $Na^+$ and $K^+$ flame photometer is used. Spectrophotometer is used to measure the sulphate ($SO_4^{2-}$), nitrate ($NO_3$), and iron (Fe). Fluoride (F) concentration is measured using ion selective electrode method and TDS is measured using the portable TDS meter. The accuracy of the results was checked using ion balance error (IBE) and it was found that the results were within +10% or -10%. The IBE was calculated using the formula (5.1).

$$Percentage\ of\ error\ (\%) = \left(\frac{(\sum Cations - \sum Anions)}{\sum Cations + \sum Cations}\right) * 100 \qquad (5.1)$$

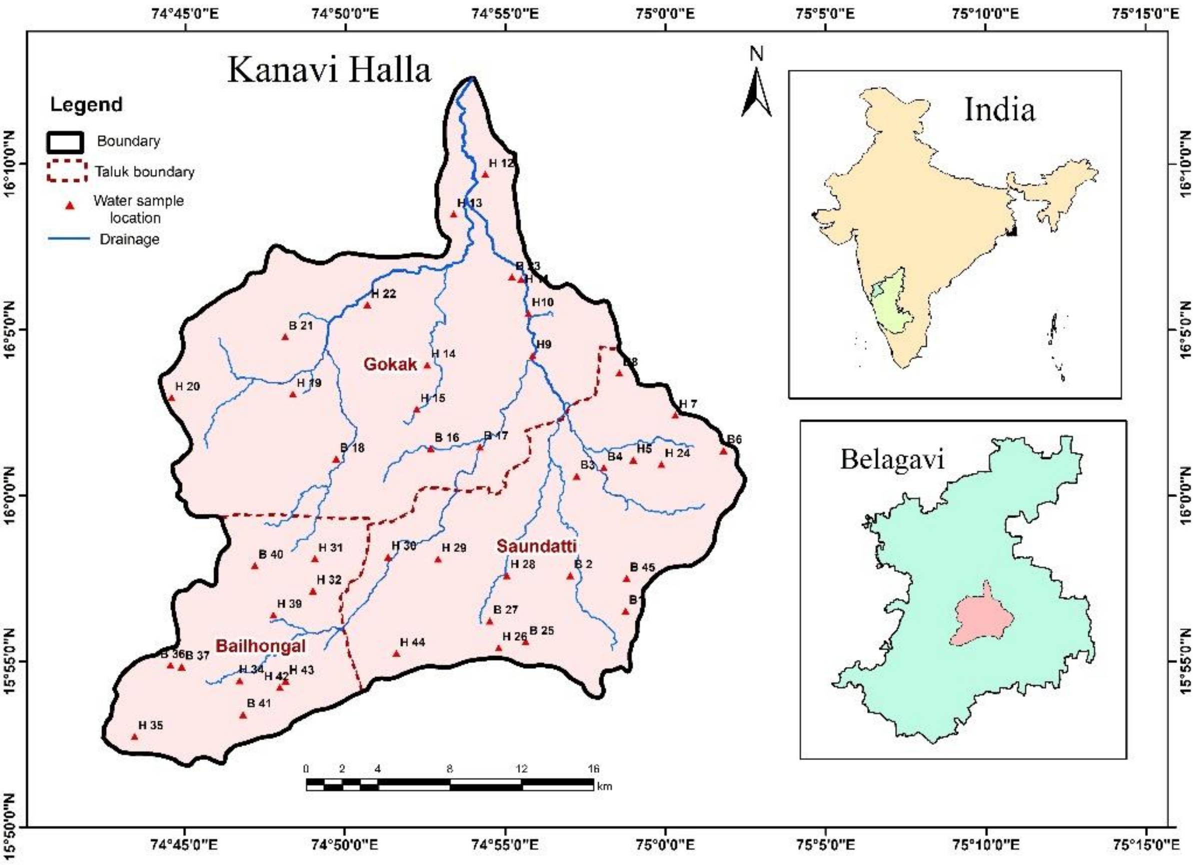



Figure.5.1 Location map of the study area

In order to find the diverse origins of mineralization in an aquifer, hydro-chemical modelling is used. To measure the degree of dissolution of ions during rock-water interactions, saturation index (SI) is calculated. If SI<0 it is under saturated water for mineral and it is dissolved, if SI=0 water is in equilibrium and if SI>0, it is supersaturated water state for mineral and also it is precipitated. Bivariate plots were used to provide more information about reactions controlling water chemistry, such as dissolution of halite, calcite, dolomite, anhydrite, gypsum aragonite and fluorite. To estimate the aqueous speciation and SI of halite, calcite, dolomite, anhydrite, gypsum and aragonite minerals were derived using "WEB-PHREEQ: Aqueous geochemical modeling". The data was analyzed using Auqchem 3.1 and WEB-PHREEQ: Aqueous geochemical modeling to get the saturation indices (SI) and other classification for agricultural suitability.

### 5.2.2 Multivariate statistical method

Multivariate statistical techniques encompass a range of statistical methods utilized for empirical investigation, shedding light on the physical and chemical attributes of groundwater systems across different spatial and temporal dimensions (Davis, 2002; Hussain et al., 2008). Conventional approaches using typical graphs and plots to decipher groundwater quality data fail to adequately depict similarities among all ions or samples concurrently (Dalton, 1978). To address this limitation, the adoption of factor analysis emerged as a solution, enabling a more effective analysis to identify resemblances among samples or variables. The application of factor analysis to the whole data set to simplify the large data set with proper arrangement and by generalizing it leads to meaningful interpretation. Statistical package for social sciences (SPSS) is used for statistical analysis and to draw the relations. As per the standard statistical procedures, the data have been standardized. The factor analysis and factors extraction were done with the PCA technique. The PCA technique is applied on water quality parameters.

### 5.2.3 Water quality index (WQI)

In the present work, fourteen parameters were considered to evaluate the suitability for drinking purpose using WQI. To get a broad picture of the groundwater quality, WQI is one of the best tools which works effectively (Mishra & Patel 2001; Subba Rao 1997). WQI is well-stated as a score displaying the combined impact of various quality factors of groundwater. To check the suitability of groundwater of drinking purposes WQI was calculated (Singh et al., 2011). The groundwater quality index (GWQI) is considered as per the to the drinking water standards (Chitsazan et al., 2017).

Following three steps have been considered to calculate WQI. Firstly, for each of the 14 parameters, weight (wi) was given according to its relative significance (Table 5.1). The least weight was given as 1 for bicarbonate and potassium since both are unimportant parameters in the quality of groundwater. The maximum weight of 5 has been given to EC, Cl, $SO_4$, and TDS as they are more significant in water quality due to their health hazards if they exceed the desirable limit. The weights between 1 and 5 have been assigned to other parameters based on their significance in groundwater quality. The Wi (relative weight) is calculated using equation 5.2.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{5.2}$$

Where wi is defined as the weight of each parameter and n is total the number of parameters. Calculated Wi values of all 14 parameters are too given in Table 5.1. Followed by the concentration of all parameters of each water sample is divided by its corresponding standard as per the rules laid down in the BIS 10500 (2012) and later it is multiplied by 100 to assign quality rating scale (qi) for each parameter, which is given as follows:

$$qi = \frac{Ci}{Si} X\ 100 \tag{5.3}$$

Where wi is defined as the weight of each parameter and n is total the number of parameters. Calculated Wi values of all 14 parameters are too given in Table 5.20(a &b). Followed by the concentration of all parameters of each water sample is divided by its corresponding standard as per the rules laid down in the BIS 10500 (2012) and later it is multiplied by 100 to assign quality rating scale (qi) for each parameter, which is given as follows.

$$SI_i = W_i * q_i \tag{5.4}$$

$$WQI = \sum SI_i \quad (5.5)$$

Where qi is the rating based on the concentration of the $i^{th}$ parameter, n is the number of parameters and SIi is the sub-index of the $i^{th}$ parameter.

Table 5.1 Relative weight of groundwater quality parameter

| Sl. No | Parameter | BIS (ISO 10500, 2012) | Weight (wi) | Relative weight $W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$ |
|---|---|---|---|---|
| 1 | pH | 6.5-8.5 | 4 | 0.083 |
| 2 | EC | 300 | 5 | 0.104 |
| 3 | TH | 200-600 | 2 | 0.042 |
| 4 | $HCO_3$ | 300- 600 | 1 | 0.021 |
| 5 | Cl | 250-1000 | 5 | 0.104 |
| 6 | $SO_4$ | 200-400 | 5 | 0.104 |
| 7 | Ca | 75-200 | 2 | 0.042 |
| 8 | Mg | 30-100 | 2 | 0.042 |
| 9 | Na | 50 – 200 | 4 | 0.083 |
| 10 | K | 10 – 12 | 1 | 0.021 |
| 11 | $NO_3$ | 45 | 4 | 0.083 |
| 12 | F | 1-1.5 | 4 | 0.083 |
| 13 | Fe | 0.3 | 4 | 0.083 |
| 14 | TDS | 500-2000 | 5 | 0.104 |
| | | | $\sum w_i = 48$ | $\sum W_i = 1$ |

### 5.2.4 Groundwater suitability for agriculture purposes and classification

Sodium and salinity hazards represent crucial chemical criteria for evaluating irrigation suitability. Elevated sodium concentrations contribute to a decline in soil permeability and increased soil hardness due to the displacement of Ca+2 and Mg+2 ions on soil clays and colloids by Na+ ions. The assessment of groundwater suitability for agricultural purposes in KHSB was initially conducted using Wilcox's classification

(1948). Subsequently, the United States Salinity Laboratory (USSL, 1954) refined the Wilcox classification system. This classification aids in determining salinity hazards, sodium hazards, and specific adverse effects caused by certain toxic components such as bicarbonates, chlorides, boron, lithium, among others. USSL classification is most suitable (Daviess and Dewiest, 1966). Therefore, knowing the quality of the groundwater for irrigation is much essential since it affects diversely for crop growths and reduces in the yield. Some mathematical results are calculated to check the quality of the groundwater for agricultural suitability in the study area. The measured parameters are electrical conductivity (Ec), sodium percentage (Na%), sodium absorption ratio(SAR), permeability index(PI), residual sodium carbonate(RSC), magnesium adsorption ratio (MAR) and Kelly's ratio (Bouderbala 2017).

For the assessment of hydro geochemistry of groundwater, Piper (1944), Stiff (1951), Durov (1948), Schoeller (1962) and Gibb's (1970) plots were used (Kumar et al., 2006; Khan and Jhariya 2018; Kant et al., 2018). Piper diagram explains the better way of the geochemical nature of the groundwater (Wasim et al., 2014; Kumar et al., 2015). AquaChem 3.70 software was used to plot the Piper, Durov and Schoeller diagram, whereas Gibb's diagram is plotted with the help of Microsoft excel. Water quality data is evaluated with the help of Piper, Schoeller and Durov plots to gain improved understanding into the hydro chemical processes functioning in the groundwater flow system (Kumar et al., 2006). The concentration of each parameter values are considered in meq/l. The entire ground water quality analysis with different approaches has been shown in figure 5.2.

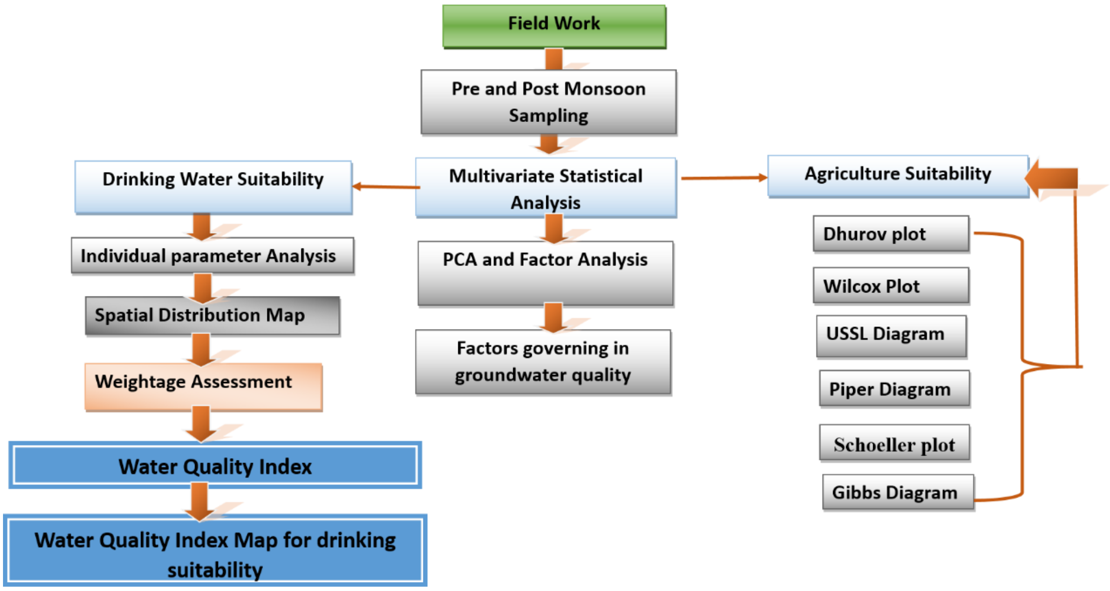



Figure 5.2 Flow chart for groundwater quality analysis

## 5.3 RESULTS AND DISCUSSION

### 5.3.1 Groundwater suitability for drinking purpose

Water being very good solvent, dissolves most of the toxic and non-toxic materials present in them which are physical, chemical and biological in nature. The quality of groundwater is of major concern in deciding the applicability of water quality from its source for drinking purposes, and it must be devoid of harmful elements, living & non-living organisms in groundwater, excessive mineral dissolution which may cause an impact on human health (Muralidhara Reddy et al. 2013, Yenugu et al. 2020). Knowing the quality of groundwater is very vital since the quality is the significant feature which decides the feasibility of water for drinking, irrigation and industries. The physical parameters include pH, EC, TDS, and TH while the chemical parameters associated with groundwater are Calcium, Magnesium, Sodium, Potassium, Carbonates, Bicarbonates, Sulphate, Chloride, Fluoride and Nitrate. The details of these physical and chemical parameters and its suitability for drinking purpose are discussed below.

Table 5.2(a) Descriptive Statistics(PRM)

| | N | Range | Min | Max | Mean | Std.Dev | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|
| **Ph** | 45 | 1.6 | 6.6 | 8.2 | 7.3 | 0.3 | 0.1 | 0.0 | 0.2 |
| **EC** | 45 | 3488 | 398 | 3886 | 1420 | 783.0 | 613113 | 1.1 | 1.0 |
| **TDS** | 45 | 2249 | 257 | 2506 | 916 | 505 | 255012 | 1.1 | 1.0 |
| **Ca** | 45 | 401 | 33.6 | 434 | 145 | 85.3 | 7279 | 1.4 | 2.2 |
| **Mg** | 45 | 118 | 0.9 | 119 | 31 | 25.7 | 662 | 1.7 | 3.4 |
| **Na** | 45 | 586 | 19 | 605 | 126 | 126.0 | 15873 | 2.1 | 4.4 |
| **K** | 45 | 247 | 0 | 247 | 23 | 56.6 | 3199 | 3.1 | 8.9 |
| **Fe** | 45 | 0.7 | 0 | 0.7 | 0.2 | 0.3 | 0.1 | 0.9 | -1.0 |
| **TH** | 45 | 1372 | 87.2 | 1460 | 470 | 277.9 | 77256 | 1.7 | 3.6 |
| **HCO3** | 45 | 534 | 122.6 | 657 | 320 | 120.1 | 14416 | 0.7 | 1.0 |
| **Cl** | 45 | 1211 | 39.9 | 1251 | 243 | 260.7 | 67989 | 2.3 | 5.7 |
| **SO4** | 45 | 193 | 10.8 | 204 | 56 | 41.7 | 1741 | 2.0 | 4.2 |
| **NO3** | 45 | 15 | 4 | 19 | 15 | 3.4 | 12 | -1.7 | 3.4 |
| **F** | 45 | 2.5 | 0.4 | 3 | 0.8 | 0.4 | 0.2 | 2.4 | 9.4 |

Table 5.2(b) Descriptive Statistics(POM)

| | N | Range | Min | Max | Mean | Std.Dev | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|
| **Ph** | 41 | 1.6 | 7.0 | 8.5 | 7.6 | 0.3 | 0.1 | 0.81 | 1.35 |
| **Ec** | 41 | 4634.0 | 355 | 4989 | 1624.1 | 986.7 | 973483.3 | 1.40 | 2.32 |
| **TDS** | 41 | 2873.1 | 220.1 | 3093.2 | 1007 | 611.7 | 374207.0 | 1.40 | 2.32 |
| **Ca** | 41 | 408.0 | 14.4 | 422.4 | 110.5 | 82.3 | 6778.4 | 1.93 | 4.69 |
| **Mg** | 41 | 157.3 | 3.9 | 161.2 | 62.4 | 35.7 | 1277.2 | 0.66 | 0.14 |
| **Na** | 41 | 804.4 | 22.6 | 827 | 174.5 | 191.6 | 36726.2 | 2.12 | 4.20 |
| **K** | 41 | 311.3 | 0 | 311.3 | 48.7 | 69.6 | 4843.8 | 2.46 | 6.68 |
| **Fe** | 41 | 0.1 | 0 | 0.1 | 0 | 0 | 0.0 | 0.68 | -0.25 |
| **TH** | 41 | 1372.3 | 95.7 | 1468 | 493 | 294.8 | 86936.3 | 1.44 | 2.83 |
| **$HCO_3$** | 41 | 704.9 | 89 | 793.9 | 331.5 | 131.7 | 17340.7 | 1.18 | 3.44 |
| **Cl** | 41 | 1217.1 | 35.8 | 1252.9 | 281.7 | 301.3 | 90790.0 | 2.11 | 4.09 |
| **$SO_4$** | 41 | 472.9 | 5.5 | 478.4 | 91.1 | 88.2 | 7787.3 | 2.53 | 8.64 |
| **$NO_3$** | 41 | 26.2 | 4 | 30.2 | 16.4 | 5.4 | 29.1 | -0.51 | 1.00 |
| **F** | 41 | 4.5 | 0.1 | 4.6 | 0.9 | 0.9 | 0.8 | 2.58 | 8.02 |

#### *5.3.1.1 pH*

The pH of water is generally the hydrogen ion concentration of water and is measured in logarithmic units as reciprocal of log 10 of hydrogen ion concentration in moles/litre

(Walton, 1970). Usually pH of any water range from 0 – 14 where pH greater than 7 indicates alkalinity of water and pH less than 7 indicates acidic nature of water, while a pH of 7 indicates neutral water. It helps in understanding the geochemical equilibrium or solubility in any water (Hem, 1985). The values of pH from the present investigation varies from 6.6 to 8.2 with an average of 7.3 during pre-monsoon and during post-monsoon it varies from 6.9 to 8.4 with an average of 7.5 (Table 5.2(a) &5.2(b)). All the groundwater samples during both the seasons are well within the standards prescribed by both BIS (2012) and WHO (2017) (Table 5.4).

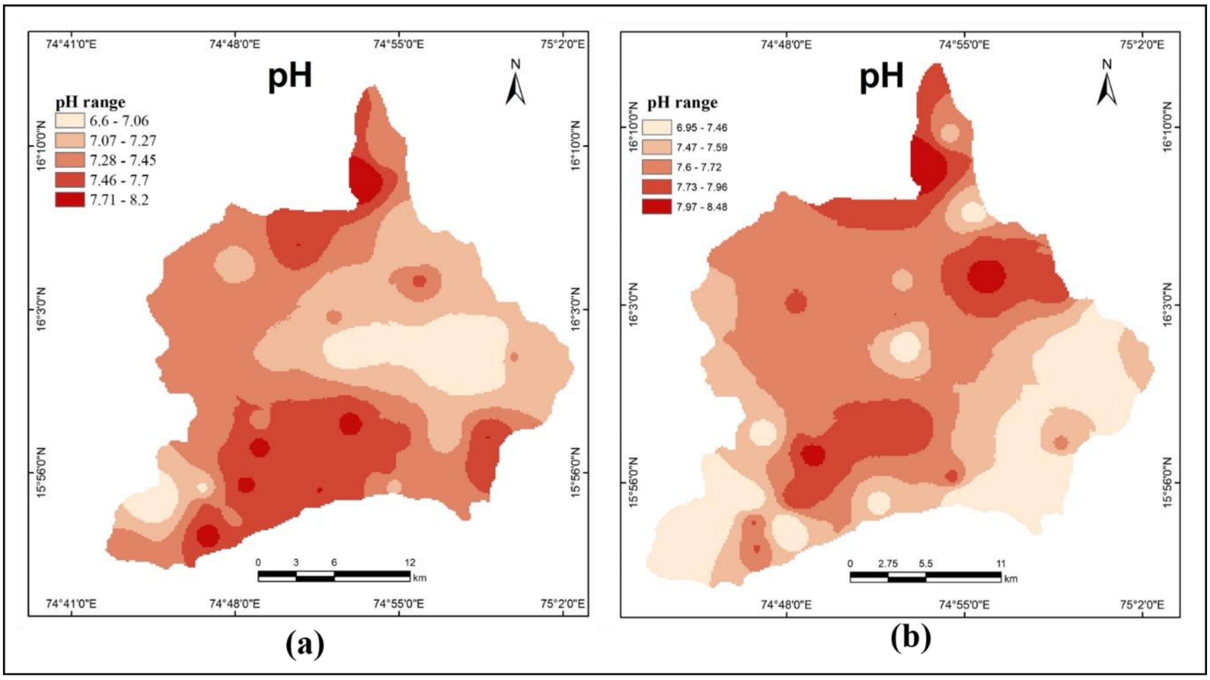



Figure 5.3 Spatial distribution maps of pH

The spatial variation map of pH (Figure 5.3) concentration in the study area for both the season that the groundwater samples are slightly more alkaline in nature from usual acidic during POM than PRM in the eastern and southern part of the study area. While in the rest of the area during both the season, the pH concentration is acidic in nature. These low values of pH can be attributed to the extensive agricultural activities in the study area where use of acid producing fertilizers and pesticides for agriculture practices (Rajesh et al. 2001; Ravikumar et al. 2010).

### *5.3.1.2 Electrical Conductivity (EC)*

Electrical Conductivity (EC) of water can be defined as the measure of salt content of water in the form of ions (Karanth, 1987) is measured in micro-siemens per centimetre (µs/cm$^2$). The presence of dissolved salts in water can be detected by measure of EC as it increases the salinity of water which affects its quality for use.

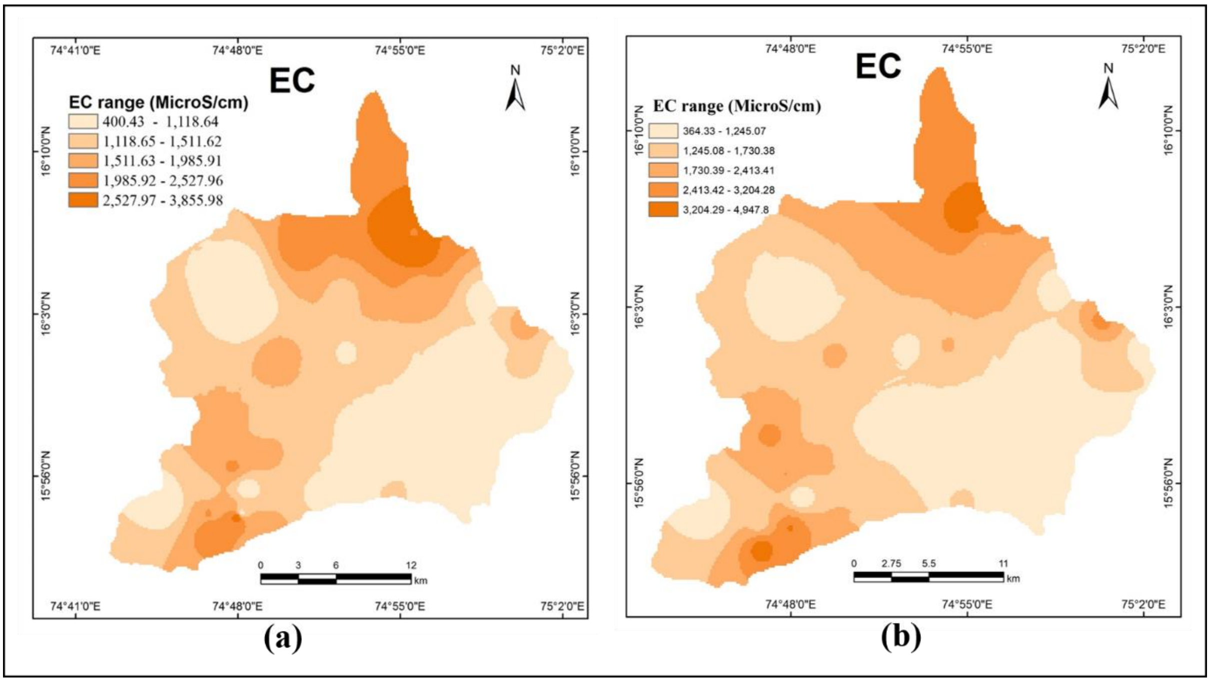



Figure 5.4 Spatial distribution maps of EC

In the present study, EC value during PRM range (Table 5.2(a) and 5.2(b)) from 398 to 3886 µs/cm$^2$ with an average of 1420 µs/cm$^2$ while during POM the EC value varies from 355 to 4989 µs/cm$^2$ with an average of 1624 µs/cm$^{2.}$ BIS (2012) standards suggests all the water samples to be suitable for drinking and domestic purpose during both season while as per WHO (2017) standards indicate 13 to 16 number of samples during PRM and POM respectively are crossing maximum allowable limits (Table 5.4).

The spatial variation map of EC during both the season are presented in figure 5.4. High concentration of EC during both the season is observed as pockets in northern and southern part of the study area. This variation in the EC in these parts is mainly due to sewage water, agriculture, geochemical processes like ion exchange, reaction between groundwater and minerals of the aquifer, evaporation, silicate mineral weathering, carbonate and soluble mineral dissolution (Harvey et. al., 2008). In the rest of the area EC supports the results of suitability for drinking purposes.

### *5.3.1.3 Total Dissolved Solids (TDS)*

Total dissolved solids (TDS) can be generally defined as the inorganic material derived from calcium, magnesium, potassium, chloride, nitrates and bicarbonates, dissolved in water. It is also observed that worldwide TDS concentrations are lower in shallow aquifers as compared to high TDS in deeper aquifer (Freeze and Cherry, 1979). TDS is one of the main criterion which determines the suitability of purposes groundwater for various.

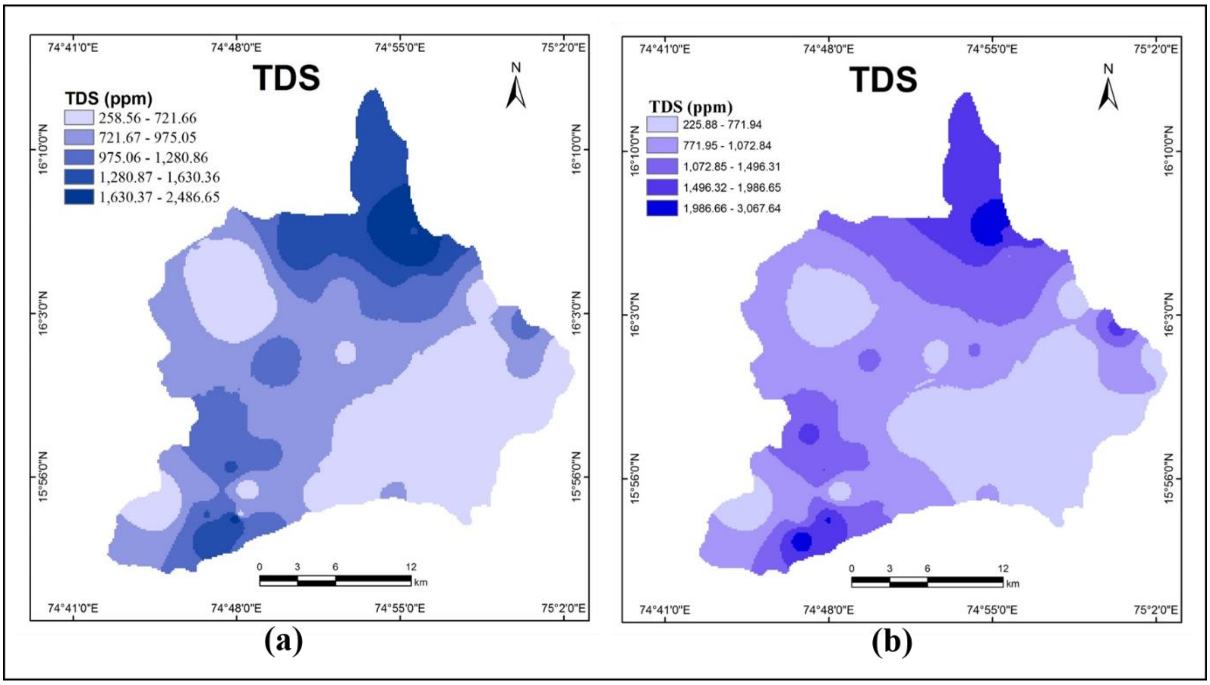



Figure 5.5 Spatial distribution maps of TDS

During pre-monsoon the TDS concentration ranges from 147 and 2550 ppm with an average of 664 ppm while during post-monsoon the TDS vary from 220 to 3093 ppm with an average of 1007 ppm (Table 5.2(a) and 5.2(b)). Based on drinking water standards of BIS (2012), it is noted that - 2 and 7 number of samples during PRM and POM respectively while 1 and 3 number of samples during PRM and POM respectively are found to be unfit for oral consumption (Table 5.4).

The spatial distribution map figure 5.5 of TDS concentration in the study area depicts few water samples as mentioned earlier which falls in the northern and southern part are having high TDS. It is also observed that the TDS is slightly increasing from PRM to POM in these samples. These higher concentrations of TDS in the groundwater are due to leaching of salts from soil and due to anthropogenic activities.

### *5.3.1.4 Total Hardness (TH)*

Total hardness (TH) in water is basically influenced by calcium and magnesium and is one of the main factors which limit, its usage for drinking and irrigation purpose (Taylor and Howard, 1995). Hardness is of two types – temporary and permanent. Temporary hardness is also called as Carbonate type, it is when small amounts of carbonates are added to calcium and magnesium. While non-carbonate or permanent hardness in water are those which are caused by addition of sulphate, chloride and nitrate ions to calcium and magnesium. Temporary hardness can be removed on boiling but doesn't hold good for permanent hardness. High concentration on TH in water is not recommended (good) for drinking and domestic purpose. Hence, process related to removal of TH from water is required. The hardness of water is usually determined in terms of $CaCO_3$.

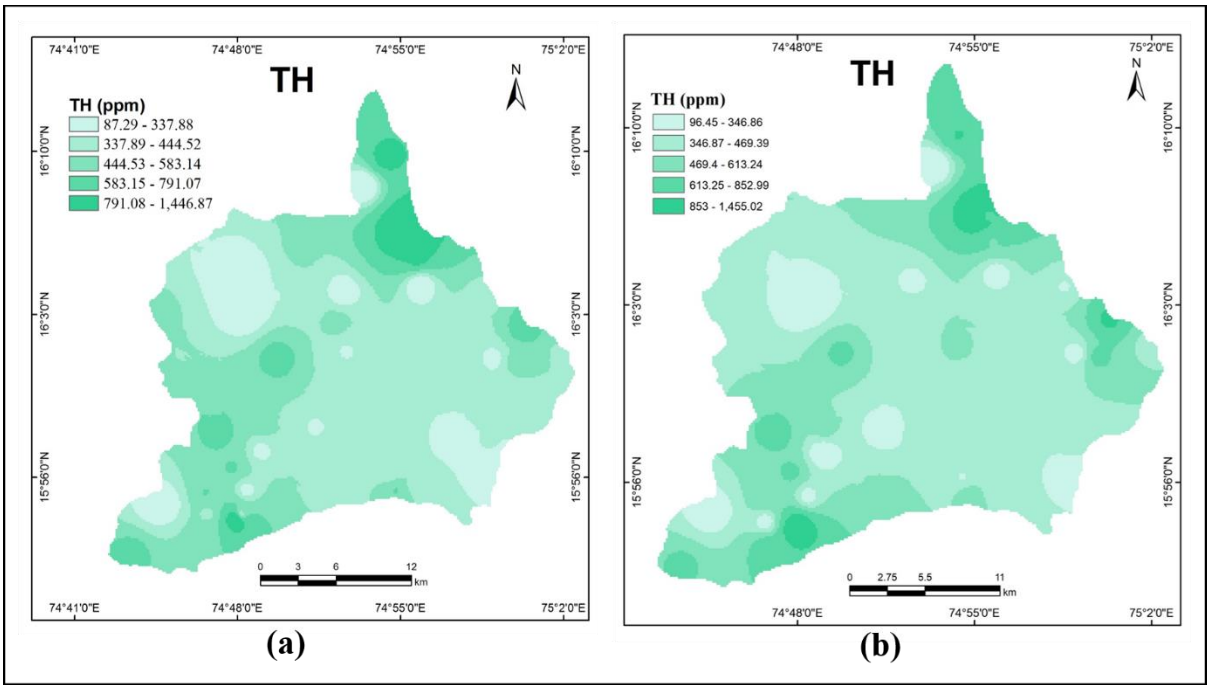



Figure 5.6 Spatial distribution maps of TH

The pre-monsoon water samples from the study area range between 87 and 1460 ppm with a mean concentration of 470 ppm while the post-monsoon water samples range between 96 and1468 ppm with mean concentration of 493 ppm (Table 5.2(a) and 5.2(b)). As per BIS (2012) standards, 13 and 17 water samples during PRM and POM respectively exceed acceptable limit of drinking standards while as per WHO (2017) 9 and 12 water samples during PRM and POM respectively exceeds maximum acceptable limits of drinking water standards (Table 5.4). Further, the hardness of the study area are classified based on Sawyer and McCarty (1967) (Table 5.3) and are observed that the water samples are very hard predominantly.

The spatial variation map of TH concentration is shown in figure 5.6. From the map it is observed that, during both seasons in north, north-west and south eastern part of the study area the concentration of TH are quite high. The groundwater samples falling under hard to very hard class is mainly due to presence of calcium and magnesium ions.

Table 5.3 Classification of hardness based on Sawyer and McCarty (1967)

| **Classification** | **Hardness** | **Water samples during PRM** | **Water samples during POM** |
|---|---|---|---|
| Soft | 0 – 75 | - | - |
| Moderately hard | 75 – 150 | 2 | 2 |
| Hard | 150 – 300 | 9 | 7 |
| Very Hard | >300 | 34 | 36 |

#### *5.3.1.5 Calcium ($Ca^{2+}$)*

Calcium ($Ca^{2+}$) is found abundantly in all natural waters. Dissolution of carbonate and sulphate minerals mainly determines the concentration of calcium ions in groundwater. Small amount of $Ca^{2+}$ is essential for growth and development of humans. But excess concentration of $Ca^{2+}$ has its effect on hardness of water and also leads to cardiovascular disease and kidney stones.

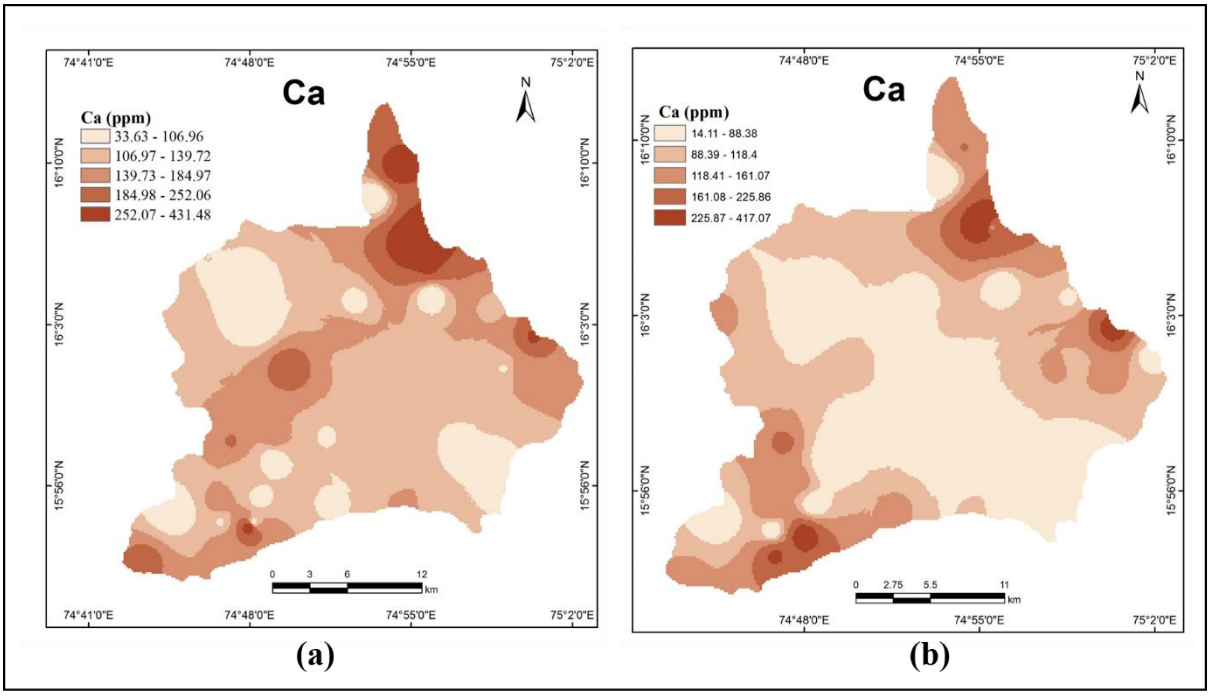


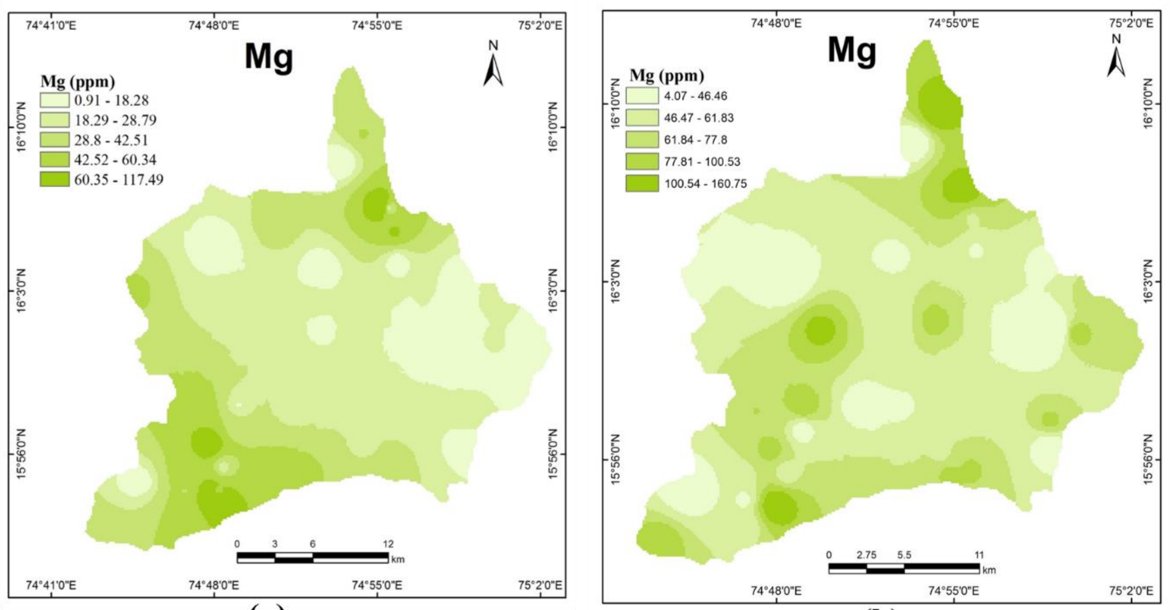

Figure 5.7 Spatial distribution maps of Ca

The calcium concentration during the PRM season vary from 84 to 1086 ppm with an average of 362 ppm while during POM it range from 14 to 422 ppm with an average of 110 ppm (Table 5.2(a) and 5.2(b)). According to BIS (2012) and WHO (2017) standards, 34 and 04 groundwater samples are found to exceeding maximum allowable limit during PRM and POM season respectively (Table 5.4). The spatial variation map of $Ca^{2+}$ concentration is presented in figure 5.7. Accordingly, it is observed that the concentration of $Ca^{2+}$ is high in the northern, western and southern part of the study area during PRM while during POM it is high in few pockets of north and south part of the study area. The high concentration of $Ca^{2+}$ during PRM may be attributed to the dissolution of dolomite and calcite mineral present in the study area and the subsequent decrease in $Ca^{2+}$ concentration during POM may be due to precipitation which diluted the concentration.

### *5.3.1.6 Magnesium ($Mg^{2+}$)*

Magnesium like calcium is also found in natural water but is generally lesser in concentration in comparison to calcium. It is derived from weathering of rocks, partly from silicates and partly from magnesium calcite and dolomite. Lower concentration of

$Mg^{2+}$ (<500 mg/l) is good for bone development but above 500 mg/l of $Mg^{2+}$ for longer period limits its use for drinking and domestic use as it has diuretic and laxative effects and also cause incrustation.




**(a)** **(b)**

Figure 5.8 Spatial distribution maps of Mg

In Kanavi Halla Sub-Basin, $Mg^{2+}$ range between 3 and 413 ppm with an average of 108 ppm during pre-monsoon season while it ranges between 4 and 161 ppm with an average of 62 ppm during post-monsoon season (Table 5.2(a) and 5.2(b)). BIS (2012) recommends the concentration of $Mg^{2+}$ in groundwater to be <150ppm for safe drinking purpose. According to this 09 and 01 groundwater samples during PRM and POM respectively were found unfit for drinking (Table 5.4).

The spatial variation map of $Mg^{2+}$ is shown in figure 5.8. The map supports the results and the higher concentration of $Mg^{2+}$ in some isolated patches during both seasons may be due to the mineral from magnesium calcite and dolomite in the study area (Sarala et al. 2012).

### *5.3.1.7 Sodium ($Na^+$)*

Sodium ($Na^+$) concentrations in the natural waters are mainly due to weathering of plagioclase feldspar. Unlike $Ca^{2+}$ and $Mg^{2+}$, $Na^+$ is not an essential constituent in many rock forming minerals. $Na^+$ concentration in the shallow groundwater is little over 50ppm which is observed in arid and semi-arid regions due to precipitation of sodium salts impregnating the soil tract. Sodium is important in the development of human body and also helps in prevention of disease related to kidneys, heart and hypertension (Rajdeo Kumar et al., 2017).

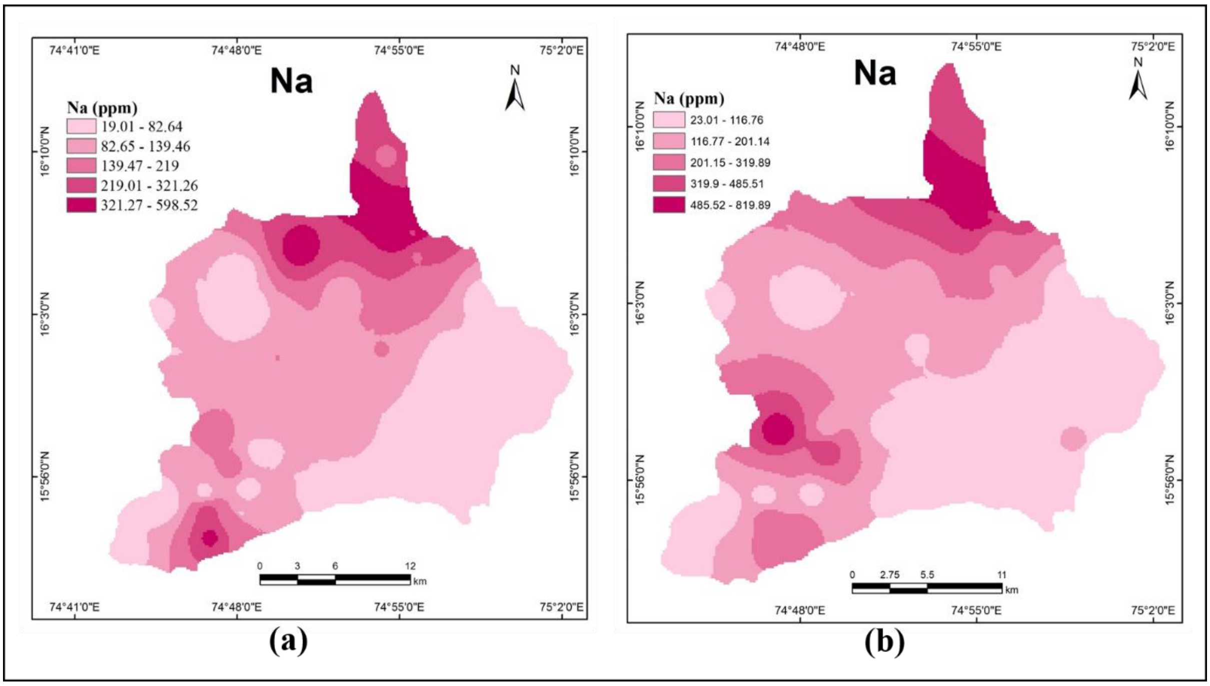



Figure 5.9 Spatial distribution maps of Na

$Na^+$ concentration in the KHSB during pre-monsoon range between 19 and 604 ppm with an average of 108 ppm wile during post-monsoon it range between 22 and 827 ppm with an average of 174 ppm (Table 5.2(a) and 5.2(b)). As per BIS (2012) standards, 8 and 7 number of groundwater samples cross the mark of maximum allowable limit for drinking suitability (Table 5.4). The spatial variation map of $Na^+$ concentration is presented in figure 5.9. The map suggests that all the water samples are within prescribed standard limits except for some isolated patches in the northern and southern part of the study area. This may be due to the feldspar minerals present in the host rock.

### *5.3.1.8 Potassium ($K^+$)*

Potassium ($K^+$) is a very common minor element in water. Usually its concentration in normal water is less than 10 ppm (Todd, 1980). It helps in understanding the hydraulic and saline nature of the aquifer (Sukhija et al., 1996). Feldspar mica and feldspathoid minerals are the main source of potassium in the groundwater. Humans are recommended regular intake of potassium for healthy heart. Excessive concentration of potassium in water leads to cathartic effect.

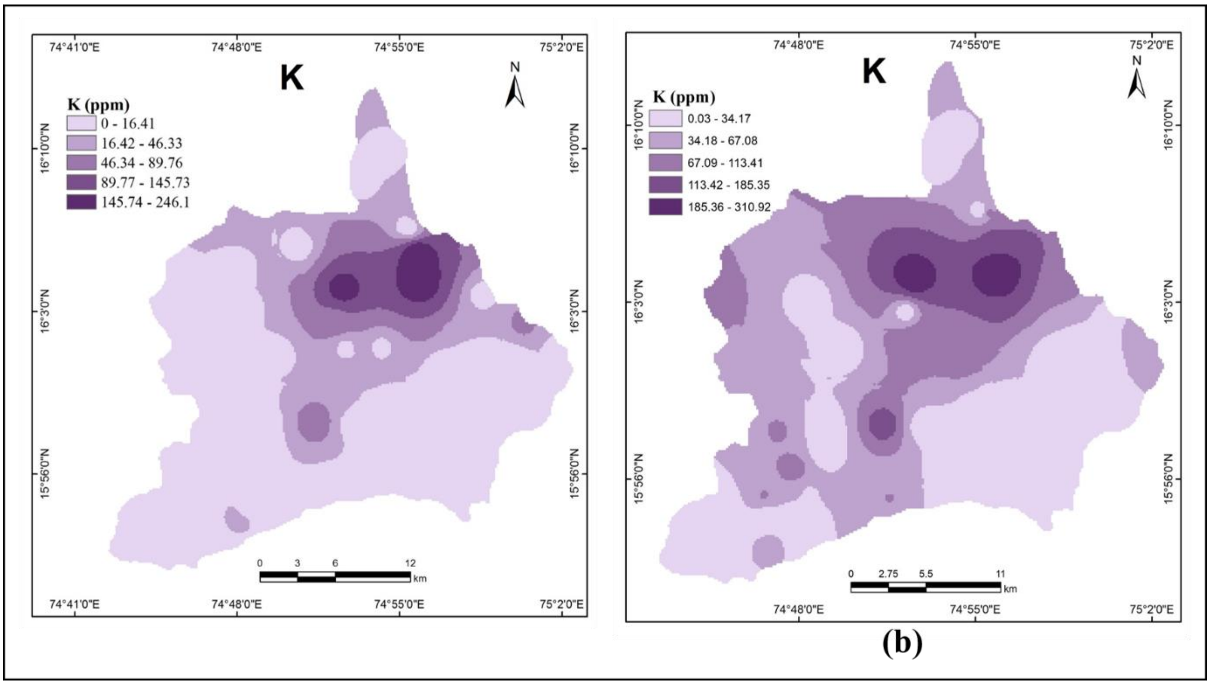



Figure 5.10 Spatial distribution maps of K

In the KHSB, potassium varies from 0 to 247 ppm with an average of 23 ppm during pre-monsoon and from 0 to 311 ppm with an average of 49 ppm during post-monsoon (Table 5.2(a) and 5.2(b)). Based on BIS (2012) standards, 7 and 11 number of groundwater samples during both PRM and POM respectively exceeds maximum allowable limits of drinking water standards (Table 5.4). The spatial variation map of potassium is presented in figure 5.10. The maps during both seasons support the BIS (2012) standards with few isolated patches in the northern part during both season exceeding allowable limit.

*5.3.1.9 Bicarbonate ($HCO_3^-$)*

Bicarbonates ($HCO_3^-$) refers to the total alkalinity of water which is a measure of its capacity to neutralise acids. Carbonate and bicarbonate concentration in the groundwater are primarily due to carbon dioxide, as it gets dissolved in rain water and reaches the groundwater through pore spaces of soil and rocks. Bicarbonate has direct relation with pH of water. Anthropogenic activities increase the alkalinity of groundwater in urban areas (Clark and Fritz, 1997).

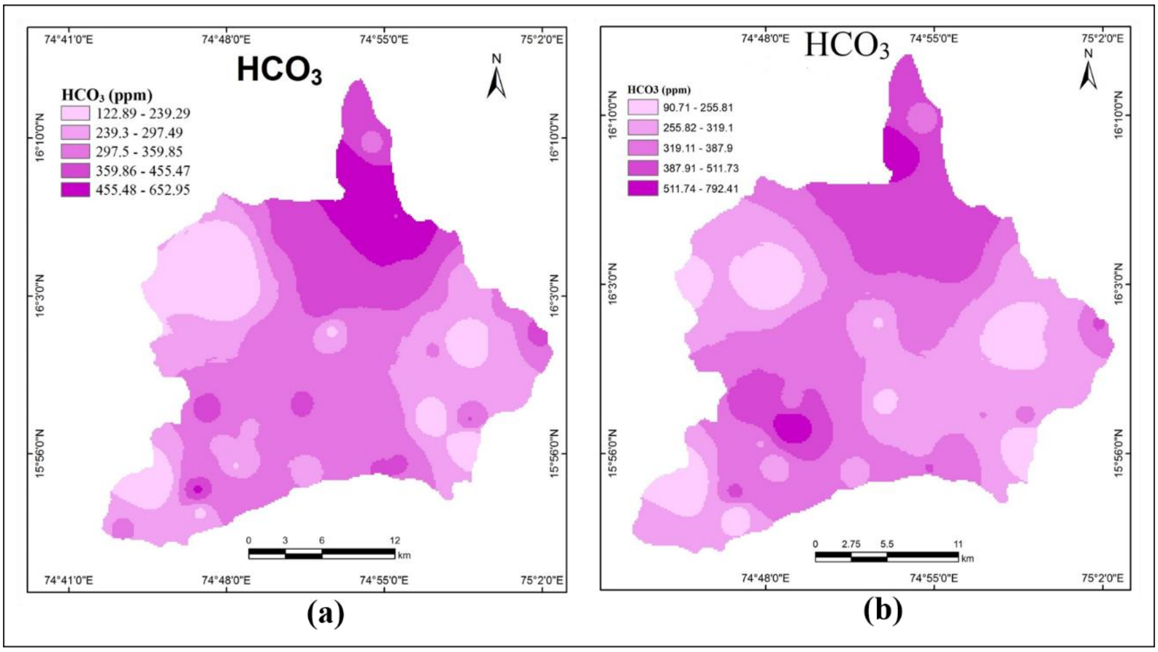



Figure 5.11 Spatial distribution maps of Alkalinity

In KHSB, the $HCO_3^-$ concentration range between 123 and 834 ppm with an average of 328 ppm during pre-monsoon and from 89 to 794 ppm with an average of 332 ppm during post-monsoon (Table 5.2(a) and 5.2(b)). According to BIS (2012) standards, $HCO_3$ concentration for maximum allowable limit is <300 ppm. Based on the above, 27 and 25 number of the groundwater samples during PRM and POM respectively are crossing maximum allowable limit. Likewise, according to WHO (2017) standard, $HCO_3$ concentration for maximum allowable is < 600 ppm. Further, based on the above, 3 and 2 number of groundwater samples during PRM and POM respectively exceed maximum allowable limit (Table 5.4). The spatial variation maps of $HCO_3^-$ are presented in figure 5.11. The map is in accordance with the standards and all the water samples are fit for domestic purposes except for the samples mentioned earlier. Further, the concentration of $HCO_3^-$ is less during PRM and POM. This may be due to dilution of rain water.

### *5.3.1.10 Chloride ($Cl^-$)*

Chloride ($Cl^-$) in natural water are primarily from three sources – sodium chloride (halite), ancient water trapped in sediments and atmospheric deposit (Walker et al., 1991). Chloride in drinking water can be attributed due to natural sources, sewage and industrial effluents, urban runoff and seawater intrusion (WHO, 2017). Usually, chloride in groundwater is present as sodium chloride but chloride concentration exceeds sodium content due to base exchange reaction.

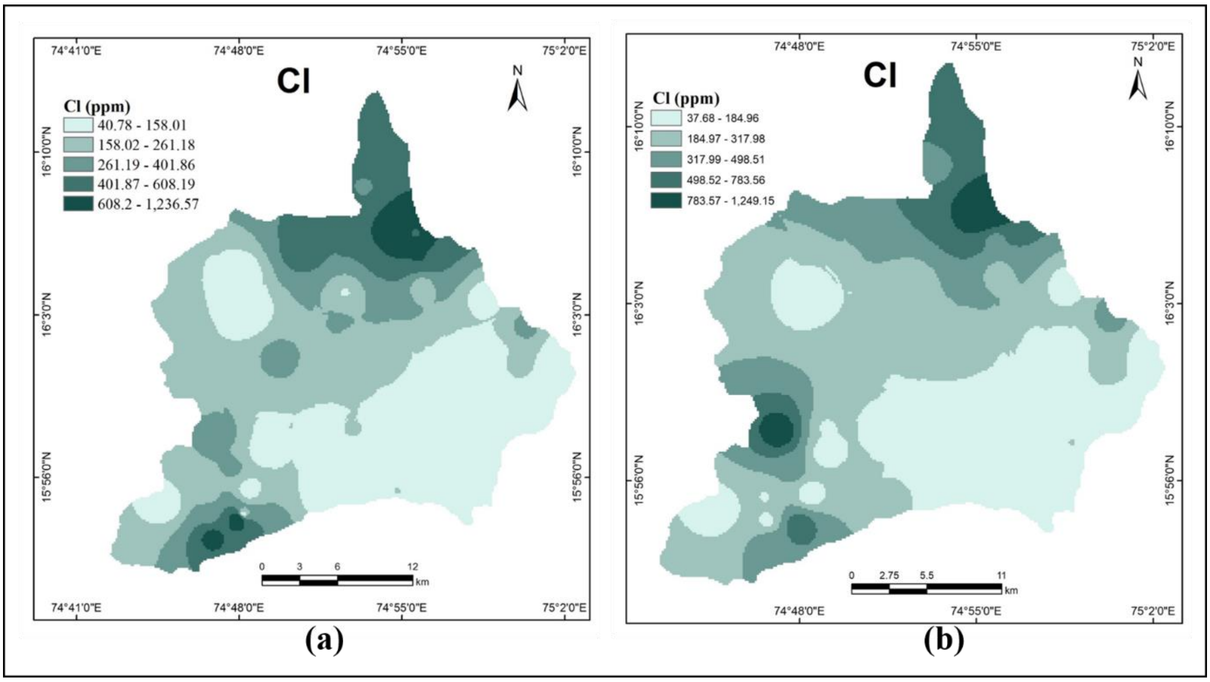



Figure 5.12 Spatial distribution maps of Cl

In the study, chloride concentrations were observed to be ranging from 18 to 1251 ppm with an average of 241 ppm during PRM and from 36 to 1253 ppm with an average of 282 ppm during POM (Table 5.2(a) and 5.2(b)). According to BIS (2012) guidelines, the maximum allowable limit of Cl- concentration for drinking should be <600 ppm. Based on the above, all the water samples fall under the permissible limit of drinking standard except for 4 and 5 groundwater samples during PRM and POM respectively which exceeds maximum allowable limit. Further, according to WHO (2017) all water samples fall under permissible limit except for 2 and 3 number of water samples during PRM and POM respectively which cross beyond maximum allowable limit (Table 5.4). The spatial variation map of Cl- is presented in figure 5.12. Accordingly, except for few changes in north and southern part of the study area during both season all the water samples are in accordance with prescribed standards. These changes in Cl- maybe attributed to the anthropogenic activities.

### *5.3.1.11 Sulphate ( $SO_4^{-2}$)*

$SO_4^{-2}$ occurs mainly in oxidized form but may also occur as sulphides. In groundwater it is formed due to oxidation, precipitation and solution as the water percolates through soil and rock (Karanth, 1987). Higher concentration of $SO_4^{-2}$ leads to corrosion of metal pipes, increase in hardness of water and in drinking water it causes gastrointestinal diseases.

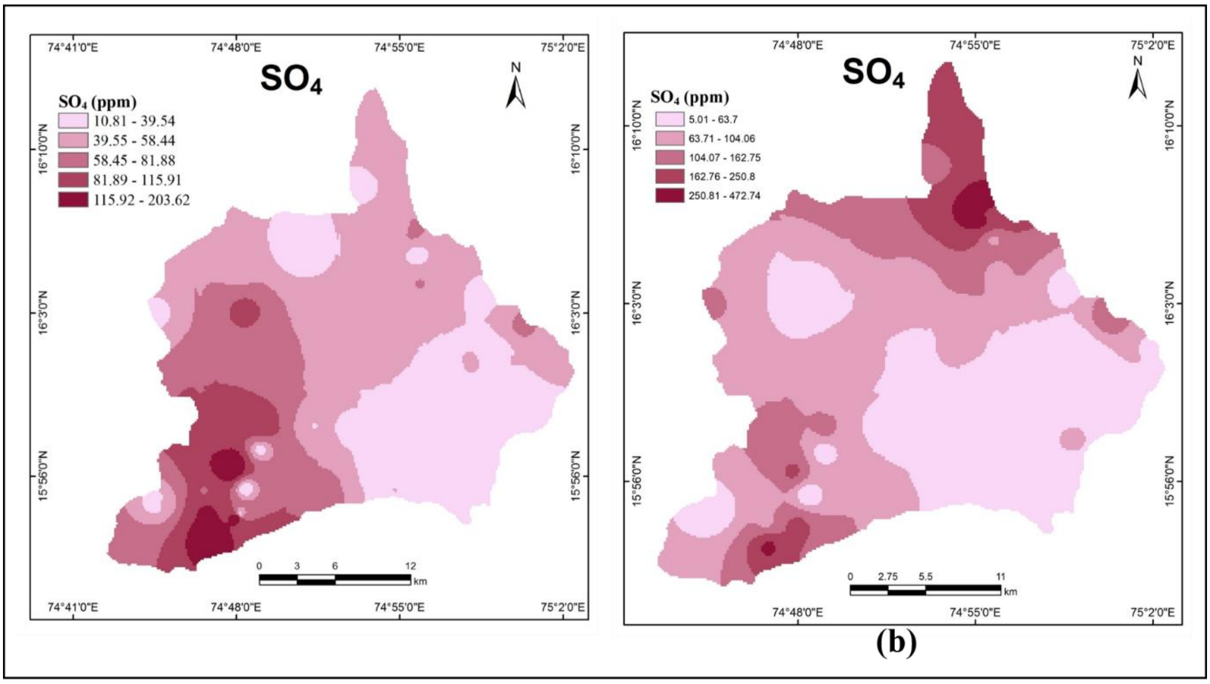



Figure 5.13 Spatial distribution maps of $SO_4$

In the present study, the $SO_4^{-2}$ concentrations vary from 11 to 204 ppm with an average of 56 ppm during PRM while it varied from 5 to 478 ppm with an average of 91 ppm during POM (Table 5.2(a) and 5.2(b)). From the comparison of BIS (2012) and

WHO (2017) guidelines which suggests the concentration of sulphate to be <400 ppm for drinking purpose. Accordingly, from the above it was observed that all the samples during both the season fall well under the prescribed standard limits (Table 5.4). The spatial variation map of sulphate concentration is shown in figure 5.13. The map shows that all the study area $SO_4^{-2}$ concentration are in accord with prescribed standards during both PRM and POM season.

### *5.3.1.12 Fluoride ($F^-$)*

Fluoride ($F^-$) in the natural waters are mainly due to weathering of minerals such as apatite, cryolite, micas, amphiboles, sellite and fluorite (Aravinthasamy et al., 2020). Fluoride is an important component for healthy growth of bones and teeth (Choi et al., 2012). Excessive consumption of $F^-$ concentrated water leads to dental and skeletal fluorosis (Susheela, 2003; Ahada and Suthar, 2017).

From the study, it is observed the $F^-$ concentration in the study area range between 0.36 and 2.83 ppm with an average of 0.81 ppm during PRM season and from 0.12 to 4.46 ppm with an average of 0.94 ppm during POM season (Table 5.2(a) and 5.2(b)). Based on BIS (2012) and WHO (2017) standards the $F^-$ concentration in drinking water is < 1.5 ppm for maximum allowable limit. According to above, 2 and 5 number of groundwater samples from PRM and POM respectively fall beyond maximum allowable limit while rest of the water samples are well within permissible limit (Table 5.4). The spatial variation map of $F^-$ concentration is shown in figure 5.14. The map suggests all the groundwater samples to be in accordance with drinking standards of BIS (2012) and WHO (2017) except for few water samples. These higher concentrations in few samples as mentioned earlier as isolated patches in northern and southern part of study area may be due to the bedrock containing fluoride minerals. Further it is also observed that $F^-$ concentration is higher during POM than PRM. It may be due to application of fertilizers in agricultural practices (Vithange and Bhattacharya, 2015).

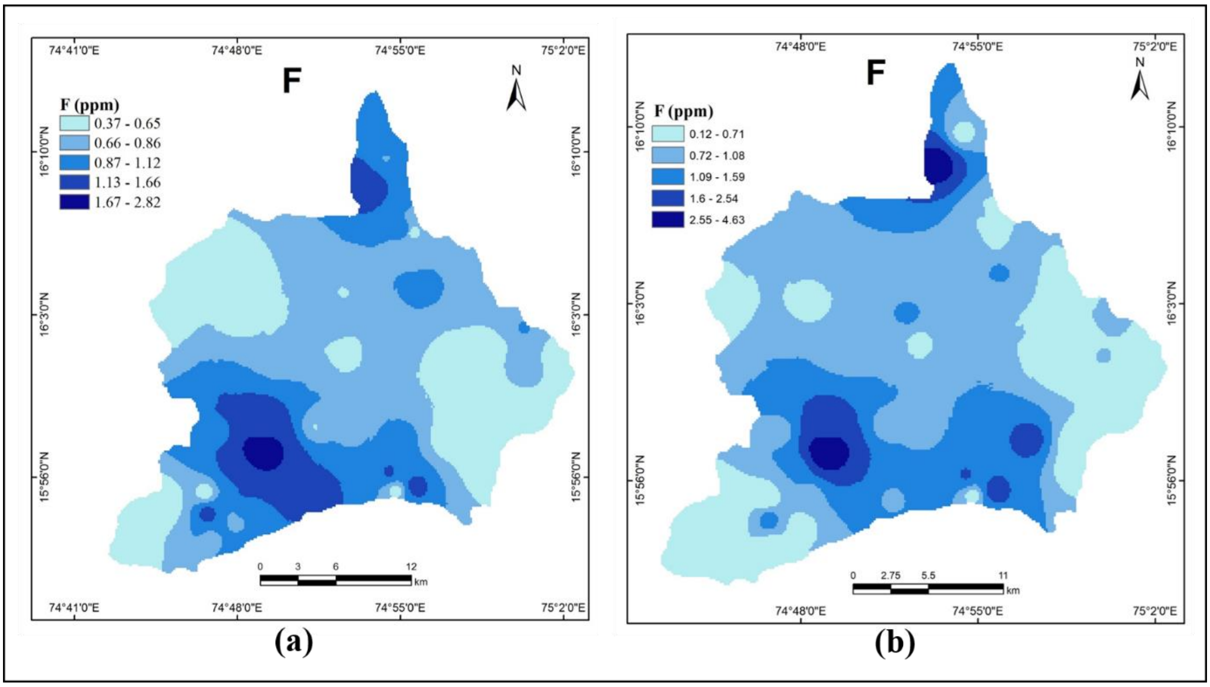



Figure 5.14 Spatial distribution maps of F

### *5.3.1.13 Nitrate ($NO_3$)*

Nitrogen from the atmosphere is the primary source of nitrate in groundwater as it reaches the surface through precipitation. The nitrate then travels through soil, plant roots, fertilizers, anthropogenic activities and industrial effluents and reaches groundwater (WHO, 2017). Generally, nitrate concentration in uncontaminated groundwater is <5ppm and in contaminated groundwater it rises upto 100ppm (Karanth, 1987). Higher concentration of NO3 results in gastric and cardiovascular diseases in adults while it leads to methemoglobinemia in infants.

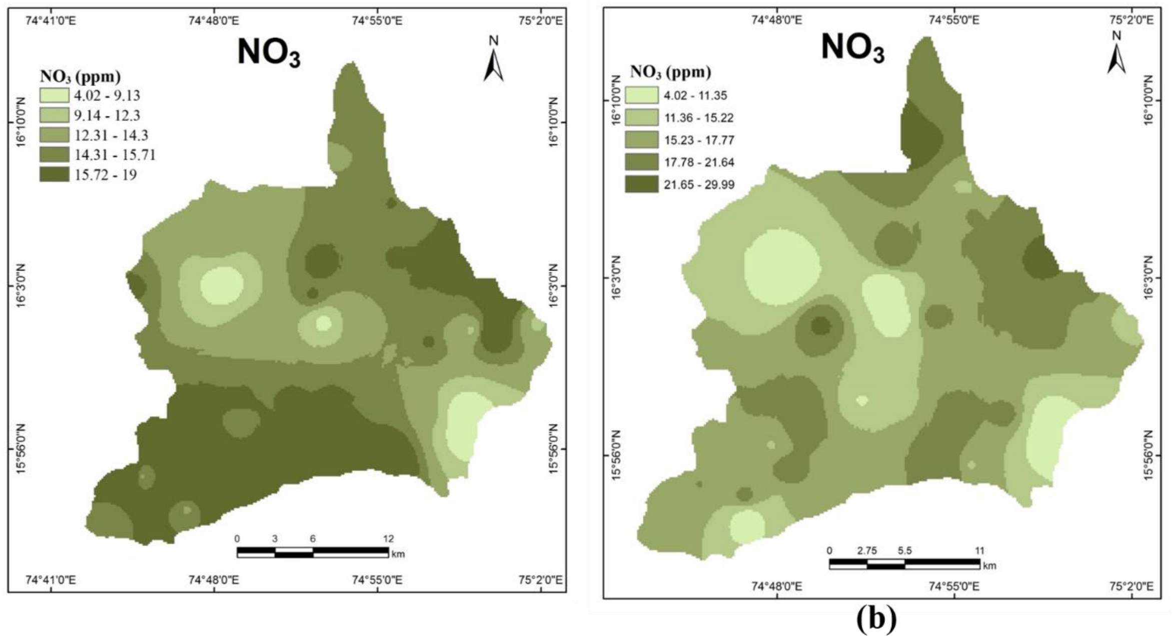



Figure 5.15 Spatial distribution maps of $NO_3$

$NO_3$ concentration in KHSB vary from 1 to 4.4 ppm with an average of 3.38 ppm during PRM season and it range from 4 to 30.2 ppm with an average of 16.4 ppm during POM season (Table 5.2(a) and 5.2(b)). Based on BIS (2012) and WHO (2017) standards for consumption of nitrate water, the prescribed limit is <40ppm. Accordingly, all the water samples from the study area are well within the prescribed limits during both PRM and POM season (Table 5.4). The spatial variation map of $NO_3$ concentration is presented in figure 5.15. The map shows that all the water samples from the study area during both seasons are in accordance with drinking standards.

#### *5.3.1.14 Iron (Fe)*

Fe in water is mainly due to dissolution of sulphates, carbonates, silicates of iron and oxides. It reaches groundwater through weathering of rock forming minerals, industrial wastes, anthropogenic activities and corrosive pipes. Iron is very essential for growth and development of human health but its deficiency or over consumption has its consequences on human health such as cardiovascular, liver and kidney problems.

In the study area, the Fe concentration range between -0.06 to 0.694 ppm with an average of 0.213 ppm during PRM season and from 0 to 0.08 ppm with an average of 0.02 ppm during POM season (Table 5.2(a) and 5.2(b)). According to BIS standard (2012), all the water samples are well within the maximum allowable limit (<1 ppm) during both season. But, WHO (2017) recommends only desirable limit (<0.3 ppm) of NO3 concentration in water. According to this, 14 groundwater samples during PRM fall under range (>0.3ppm) greater than desired limit. During POM season, all water samples are well within stipulated limits (Table 5.4). The spatial variation of Fe concentration is presented in figure 5.16. The maps of both the season are in accord with prescribed standard during both season and the values of Fe during POM season are low as compared to during PRM season.

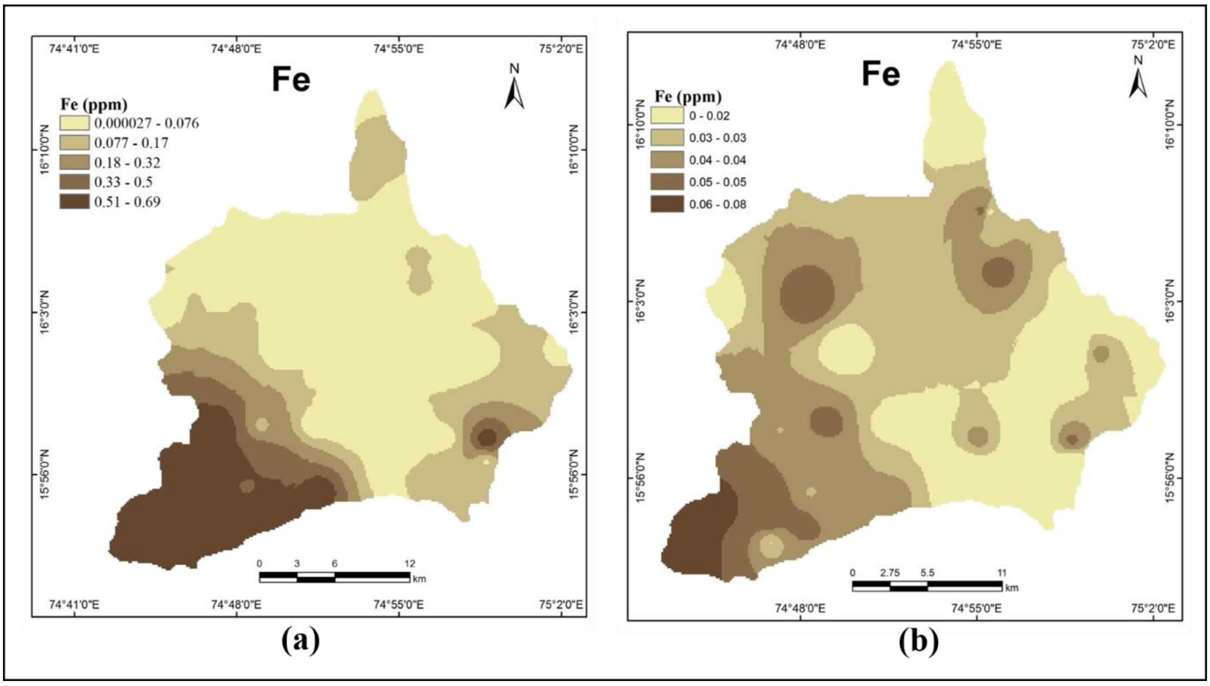



Figure 5.16 Spatial distribution maps of Fe

Table 5.4 Groundwater samples above the permissible limits prescribed by WHO and BIS (After Subramani et al., 2005; Khan and Jhariya, 2018)

| Sl No. | Parameters | BIS (2012) | | | | WHO (2017) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Permissible Limit | Allowable Limit | No. of samples exceeding allowable limit during PRM | No. of samples exceeding allowable limit during POM | Permiss-ible Limit | Allowable Limit | No. of samples exceeding allowable limit during PRM | No. of samples exceeding allowable limit during POM | Undesir-able effect |
| 1 | Ph | 6.5-8.5 | - | Nil | | 6.5-8 | 9.2 | Nil | Nil | Taste |
| 2 | Ec µS/cm | - | - | - | - | | 1500 | KHSB-7,9,10,11,12,13,18,22,23,32,34,39,42 | KHSB-7,9 10,11,12,13,14,17,18,23,24,32,35,39,40,41,42,44 | - |
| 3 | TH (mg/l) | 200 | 600 | KHSB-7,10,11,12, 18,23,35,39,40,42 | KHSB-7,10,11,12,18,23,24,35,39,40,41,42 | 100 | 500 | KHSB-7,10,11,12,15,18,23,26,35,38,39,40,41,42 | KHSB-7,10,11,12,17,18,23, | Scale formation |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 24,26,31,35,38,39,40,41,42,44 | |
| 4 | Cl (mg/l) | 250 | 1000 | KHSB-23,42 | KHSB-11,23,40 | 200 | 600 | KHSB-10,23,41,42 | KHSB-11,12,23,40,42 | Salty taste, corrosion |
| 5 | TDS | 500 | 2000 | KHSB- 23 | KHSB-23,41,42 | 500 | 1500 | KHSB-10,12,13,22,23,41,42 | KHSB-7,11,12,13,23,40,41,42 | Gastrointestinal irritation |
| 6 | Ca (mg/l) | 75 | 200 | KHSB-7,10,11,12,18,23,35,42 | KHSB-7,23,41,42 | 75 | 200 | KHSB-7,10,11,12,18,23,35,42 | KHSB-7,23,41,42 | Scale formation |
| 7 | Mg (mg/l) | 30 | 100 | KHSB-23,42 | KHSB-11,12,18,23,42 | 50 | 150 | Nil | KHSB-42 | |
| 8 | Na (mg/l) | - | - | - | - | - | 200 | KHSB-10,11,13,22,23,34,41,42 | KHSB-10,11,12,13,2332,34,39,40,41,42 | - |
| 9 | K (mg/l) | - | - | - | - | - | 30 | KHSB-7,9,10,14,15,30,42 | KHSB-6,8,9,10,11,14,16,17,20,30,33,38,39,40,4144 | - |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Fe (mg/l) | 0.3 | - | KHSB-32,33,34,35,36,37,38,39,40,41,42,43,4,45, | Nil | 0.3 | 1.0 | | Nil | - |
| 11 | F (mg/l) | 1 | 1.5 | KHSB-13,32 | KHSB-2,13,25,27,31,32, | - | 1.5 | KHSB-13,32 | KHSB-2,13,25,27,31,32, | Fluorosis |
| 12 | $NO_3$ (mg/l) | 45 | - | Nil | Nil | 45 | 50 | Nil | Nil | Blue baby |
| 13 | $HCO_3$ (mg/l) | 600 | - | | KHSB-13,32 | - | 300 | 3,6,7,9,10,11,12,13,14,15,17,18,22,23,25,26,27,28,29,30,34,35,38,40,42,43,45 | KHSB-2,6,9,10,11,12,13,14,15,17,18,23,25,26,30,31,32,34,35,38,39,40,42,44,45 | - |
| 14 | $SO_4$ (mg/l) | 200 | 400 | Nil | | 200 | 400 | Nil | KHSB-23 | Laxative effect |

### 5.3.2 Assessment of groundwater quality for agricultural use

In agriculture, quality and quantity of water plays an important role as it determines crop yield (Tiwari et al., 2016). In the study, assessment of groundwater quality for agricultural use was done by considering following parameters – Sodium Absorption Ratio, Sodium percent, Residual Sodium Carbonate, Magnesium Ratio, Permeability Index and Kelley's Ratio. In the following sub-sections these parameters are discussed in detail. The results of these parameters are presented in Table 5.5(a) and Table 5.5(b) during both PRM and POM.

Table 5.5(a) Results of irrigational parameters for KHSB during pre-monsoon

| Sample No. | SAR | Na% | RSC | MR | PI | KR |
|---|---|---|---|---|---|---|
| KHSB 1 | 0.55 | 17 | -2.0 | 11 | 45 | 0.2 |
| KHSB 2 | 1.13 | 27 | -2.6 | 32 | 49 | 0.3 |
| KHSB 3 | 1.04 | 22 | -2.8 | 12 | 43 | 0.3 |
| KHSB 4 | 1.26 | 26 | -4.1 | 11 | 43 | 0.3 |
| KHSB 5 | 0.75 | 20 | -3.0 | 8 | 42 | 0.2 |
| KHSB 6 | 1.34 | 25 | -2.2 | 2 | 47 | 0.3 |
| KHSB 7 | 0.80 | 20 | -10.4 | 15 | 25 | 0.1 |
| KHSB 8 | 0.96 | 20 | -2.7 | 13 | 44 | 0.3 |
| KHSB 9 | 5.72 | 81 | 4.3 | 27 | 97 | 2.3 |
| KHSB 10 | 2.96 | 45 | -10.0 | 28 | 43 | 0.5 |
| KHSB 11 | 4.36 | 44 | -8.7 | 11 | 53 | 0.8 |
| KHSB 12 | 2.78 | 31 | -13.1 | 19 | 40 | 0.5 |
| KHSB 13 | 20.46 | 92 | 8.7 | 4 | 107 | 10.9 |
| KHSB 14 | 2.46 | 66 | 2.0 | 10 | 76 | 0.8 |
| KHSB 15 | 2.54 | 42 | -3.5 | 16 | 52 | 0.6 |
| KHSB 16 | 2.34 | 40 | -3.0 | 20 | 57 | 0.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| KHSB 17 | 3.15 | 45 | -2.3 | 25 | 61 | 0.8 |
| KHSB 18 | 2.26 | 30 | -9.2 | 14 | 41 | 0.4 |
| KHSB 19 | 0.70 | 22 | -1.6 | 39 | 50 | 0.2 |
| KHSB 20 | 1.50 | 25 | -6.8 | 36 | 39 | 0.3 |
| KHSB 21 | 1.31 | 35 | -1.9 | 15 | 57 | 0.5 |
| KHSB 22 | 7.83 | 64 | -3.6 | 32 | 73 | 1.8 |
| KHSB 23 | 6.73 | 46 | -19.8 | 29 | 52 | 0.9 |
| KHSB 24 | 1.09 | 19 | -5.9 | 19 | 36 | 0.2 |
| KHSB 25 | 1.50 | 27 | -2.5 | 34 | 48 | 0.4 |
| KHSB 26 | 1.09 | 18 | -6.1 | 28 | 35 | 0.2 |
| KHSB 27 | 1.04 | 21 | -2.5 | 26 | 45 | 0.3 |
| KHSB 28 | 1.29 | 24 | -3.2 | 22 | 44 | 0.3 |
| KHSB 29 | 2.51 | 38 | -3.5 | 26 | 54 | 0.6 |
| KHSB 30 | 2.56 | 51 | -0.4 | 25 | 63 | 0.7 |
| KHSB 31 | 2.19 | 33 | -4.9 | 15 | 48 | 0.5 |
| KHSB 32 | 0.68 | 18 | -1.1 | 45 | 48 | 0.2 |
| KHSB 33 | 0.89 | 21 | -1.7 | 33 | 49 | 0.3 |
| KHSB 34 | 6.05 | 60 | -0.6 | 41 | 73 | 1.5 |
| KHSB 35 | 0.89 | 14 | -9.1 | 20 | 28 | 0.2 |
| KHSB 36 | 1.02 | 33 | -1.5 | 14 | 57 | 0.4 |
| KHSB 37 | 0.96 | 27 | -2.0 | 23 | 52 | 0.3 |
| KHSB 38 | 0.88 | 15 | -7.1 | 33 | 31 | 0.2 |
| KHSB 39 | 3.04 | 37 | -8.7 | 54 | 47 | 0.6 |
| KHSB 40 | 2.92 | 35 | -8.0 | 34 | 47 | 0.5 |
| KHSB 41 | 6.66 | 58 | -8.2 | 34 | 65 | 1.4 |
| KHSB 42 | 2.38 | 27 | -21.7 | 36 | 31 | 0.3 |
| KHSB 43 | 1.52 | 29 | -1.6 | 55 | 52 | 0.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| KHSB 44 | 1.19 | 22 | -4.4 | 49 | 40 | 0.3 |
| KHSB 45 | 1.24 | 25 | -1.4 | 30 | 49 | 0.3 |

Table 5.5(b) Results of irrigational parameters for KHSB during post-monsoon

| Sample No. | SAR | Na% | RSC | MR | PI | KR |
|---|---|---|---|---|---|---|
| KHSB 1 | 1.45 | 25 | -1.2 | 51 | 53 | 0.2 |
| KHSB 2 | 1.00 | 22 | -2.5 | 54 | 42 | 0.2 |
| KHSB 4 | 0.61 | 32 | -3.4 | 20 | 48 | 0.4 |
| KHSB 5 | 1.11 | 25 | -2.5 | 6 | 46 | 0.3 |
| KHSB 6 | 0.63 | 36 | -1.3 | 65 | 49 | 0.4 |
| KHSB 7 | 0.66 | 21 | -14.2 | 30 | 29 | 0.2 |
| KHSB 8 | 0.92 | 36 | -1.5 | 45 | 48 | 0.3 |
| KHSB 9 | 0.20 | 75 | 4.0 | 69 | 83 | 1.5 |
| KHSB 10 | 0.28 | 49 | -4.4 | 37 | 55 | 0.7 |
| KHSB 11 | 0.15 | 56 | -7.7 | 58 | 62 | 1.2 |
| KHSB 12 | 0.20 | 46 | -11.9 | 57 | 53 | 0.8 |
| KHSB 13 | 0.03 | 94 | 11.3 | 66 | 105 | 14.7 |
| KHSB 14 | 0.28 | 68 | 2.1 | 45 | 73 | 1.0 |
| KHSB 15 | 0.28 | 47 | -2.4 | 51 | 62 | 0.9 |
| KHSB 16 | 0.44 | 49 | -2.6 | 51 | 55 | 0.6 |
| KHSB 17 | 0.31 | 45 | -4.1 | 64 | 54 | 0.7 |
| KHSB 18 | 0.39 | 32 | -7.7 | 65 | 44 | 0.5 |
| KHSB 19 | 0.94 | 34 | -0.6 | 35 | 64 | 0.4 |
| KHSB 20 | 0.49 | 40 | -5.2 | 36 | 46 | 0.5 |
| KHSB 23 | 0.11 | 54 | -20.9 | 32 | 59 | 1.2 |
| KHSB 24 | 1.09 | 16 | -8.9 | 53 | 29 | 0.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| KHSB 25 | 0.65 | 27 | -2.4 | 67 | 46 | 0.3 |
| KHSB 26 | 0.94 | 19 | -4.5 | 55 | 36 | 0.2 |
| KHSB 27 | 0.94 | 23 | -1.8 | 62 | 47 | 0.3 |
| KHSB 28 | 0.72 | 26 | -2.1 | 54 | 49 | 0.3 |
| KHSB 29 | 1.02 | 22 | -3.4 | 44 | 41 | 0.2 |
| KHSB 30 | 0.49 | 57 | 1.5 | 39 | 68 | 0.6 |
| KHSB 31 | 0.42 | 33 | -5.0 | 67 | 48 | 0.5 |
| KHSB 32 | 0.06 | 86 | 12.7 | 77 | 104 | 6.2 |
| KHSB 33 | 1.05 | 29 | -0.7 | 68 | 52 | 0.3 |
| KHSB 34 | 0.13 | 70 | 3.4 | 62 | 87 | 2.3 |
| KHSB 35 | 0.95 | 18 | -8.2 | 56 | 31 | 0.2 |
| KHSB 36 | 0.79 | 43 | -0.7 | 37 | 70 | 0.6 |
| KHSB 37 | 0.70 | 30 | -3.0 | 45 | 48 | 0.4 |
| KHSB 38 | 1.01 | 26 | -5.2 | 35 | 35 | 0.2 |
| KHSB 39 | 0.30 | 44 | -8.3 | 51 | 48 | 0.6 |
| KHSB 40 | 0.10 | 67 | -7.2 | 42 | 72 | 1.9 |
| KHSB 41 | 0.28 | 41 | -12.4 | 24 | 46 | 0.6 |
| KHSB 42 | 0.36 | 27 | -21.4 | 46 | 34 | 0.4 |
| KHSB 44 | 0.69 | 30 | -6.1 | 44 | 38 | 0.3 |
| KHSB 45 | 0.34 | 40 | -2.9 | 71 | 56 | 0.7 |

#### 5.3.2.1 Sodium Absorption Ratio (SAR)

SAR is an important parameter to evaluate the suitability of water irrigation (Karanth, 1987). SAR is the measure of amount of sodium to calcium and magnesium in water (Richards, 1954). Excessive sodium replacing Ca and Mg becomes hazard as it detoriate soil structure and make it impervious, therefore hampering the permeability thus insufficient water for growth of crops. SAR is calculated using the formula 5.6.

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad (5.6)$$

Where all values are expressed in epm.

The calculated SAR value for both seasons is presented in Table 6 and 7. Based on the above, the SAR concentration of the KHSB classified. From the classification it is observed that all the water samples during both seasons fall under the class Excellent for irrigational use (Table 5.6)

Table 5.6 Classification based on SAR

| SAR Value | Water Class | No. of samples during PRM | No. of samples during POM |
|---|---|---|---|
| <10 | Excellent | 45 | 41 |
| 10 -18 | Good | - | - |
| 18 – 26 | Doubtful | - | - |
| >26 | Unsuitable | - | - |

***5.3.2.2 Salinity Hazard***

The US Salinity Laboratory (1954) has used salinity and sodium hazards as the two important criteria in the evaluation of waters for irrigation purpose. Therefore, Salinity and sodium hazard is calculated by graphically plotting SAR against EC. In the diagram, C1, C2, C3, C4 represents salinity hazard while S1, S2, S3, S4 represents sodium hazard (Figure 5.17).

From the diagram, it reveals that, during PRM 32 water samples fall under class (C3-S1) followed by 7 samples falling under class C2-S1 and 3 samples each falling under class C4-S1, C3-S2 and C4-S2. While during POM, 29 water samples fall under class C3-S1, followed by 8 samples each under class C2-S1 and C4-S1 (Figure 5.17)(a) and 5.17(b)).

High salinity is found in most of the water samples during both seasons. This may be attributed to uncontrolled use of fertilizers and pesticides in agriculture practices.

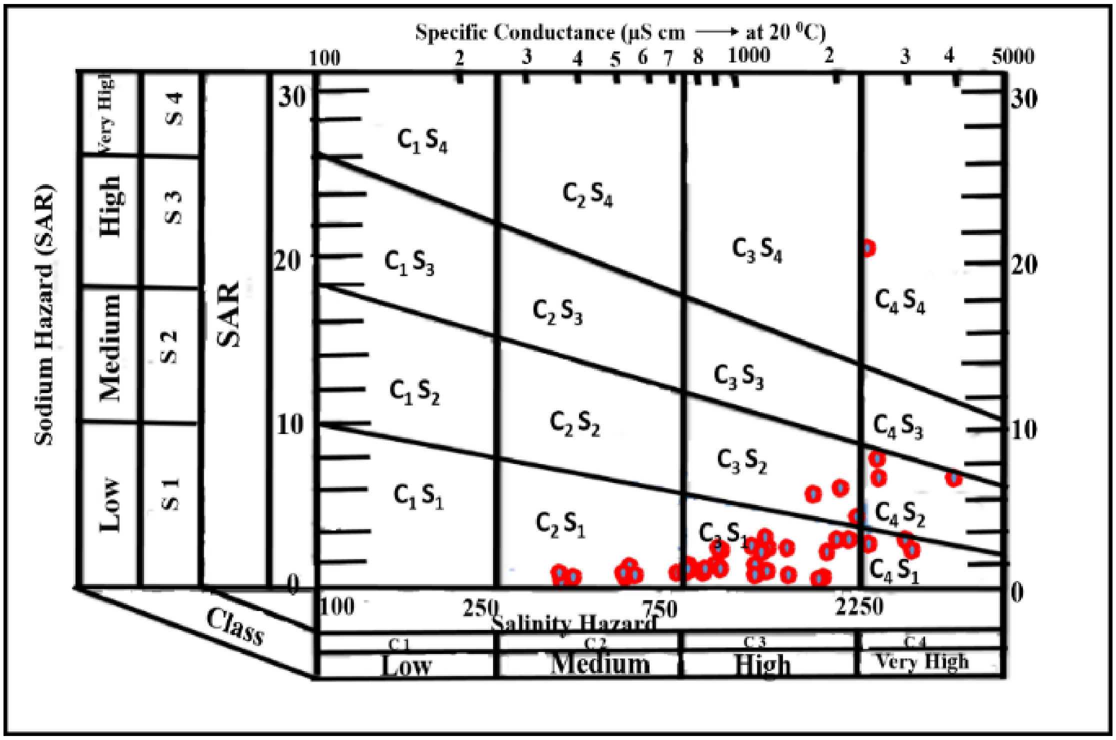



Figure 5.17(a) USSL diagram for irrigated waters of KHSB during pre-monsoon

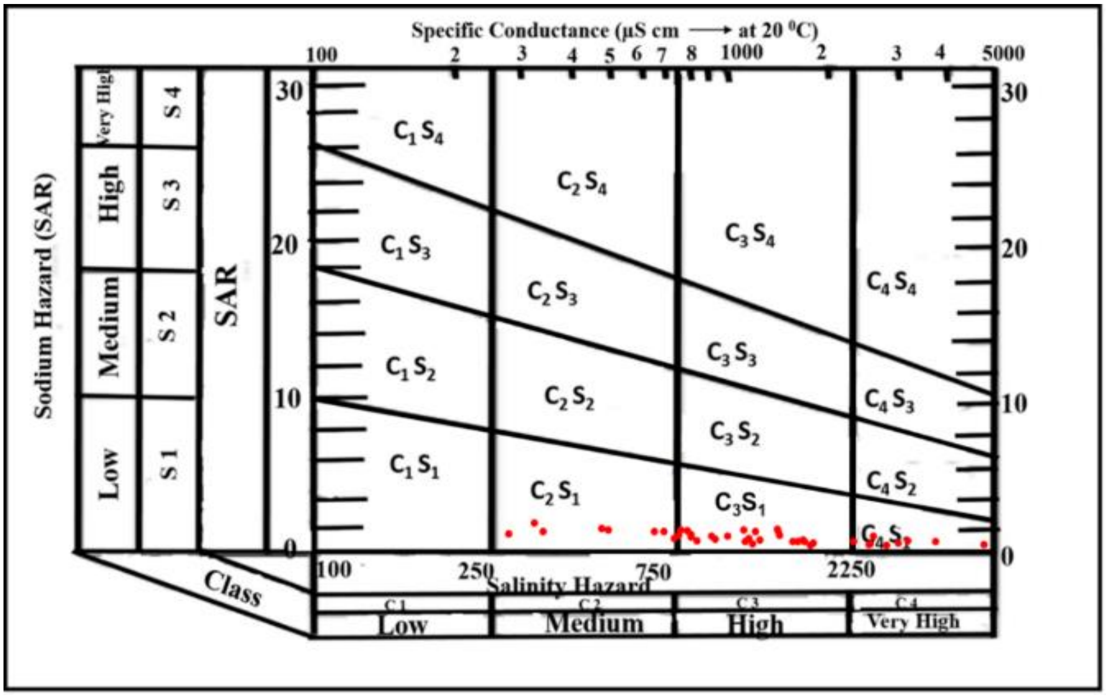



Figure 5.17(b) USSL diagram for irrigated waters of KHSB during Post Monsoon

### *5.3.2.3 Sodium Percent (Na%)*

Sodium and potassium plays very vital role in classifying irrigation water because sodium by the process of Base Exchange replaces Ca and Mg in the soil thereby reducing its permeability which results in lesser plant growth and low crop yield (Saleh et al. 1999). This sodium concentration is expressed as sodium percent and is calculated using the formula 5.7.

$$Na\% = \frac{(Na + K) * 100}{(ca + Mg + Na + K)} \tag{5.7}$$

Where all values are expressed in epm

The calculated values of Na% is tabulated in Table 5.5(a) and 5.5(b). The suitability of groundwater samples were classified based on Na% values (Table 5.7). From the classification it was observed that, 09 water samples fall under class Excellent; 24 samples fall under class Good; 08 samples under Permissible and 02 samples each fall under class: Doubtful and Unsuitable during pre-monsoon. During post-monsoon, 03 water samples fall under class Excellent; 19 samples fall under Good class; 11 samples fall under class Permissible followed by 04 and 02 samples in class: Doubtful and Unsuitable respectively (Table 5.7).

Table 5.7 Classification based on Na% concentration

| **Na%** | **Class** | **No. of samples during PRM** | **No. of samples during POM** |
|---|---|---|---|
| <20 | Excellent | 09 | 03 |
| 20-40 | Good | 24 | 19 |
| 40-60 | Permissible | 08 | 11 |
| 60-80 | Doubtful | 02 | 04 |
| >80 | Unsuitable | 02 | 02 |

#### *5.3.2.4 Wilcox Classification*

Wilcox (1955) introduced a graphical interpretation of suitability of irrigated water based on plotting of sodium percent against electrical conductivity. This graph is also called a Wilcox diagram. The results of Na% calculated for KHSB were plotted against EC and the study reveals that, during PRM 14 groundwater samples are found to be in the class- Good to Permissible followed by 24 samples falling under class-Doubtful to Unsuitable and 03 sample falling under class- Unsuitable. Further, during POM, 20 groundwater samples are found to be in the class-Good to Permissible followed by 24 samples under class- Doubtful to Unsuitable and 01 sample falling under class- Unsuitable (Figure 5.18(a) and 5.18(b)).

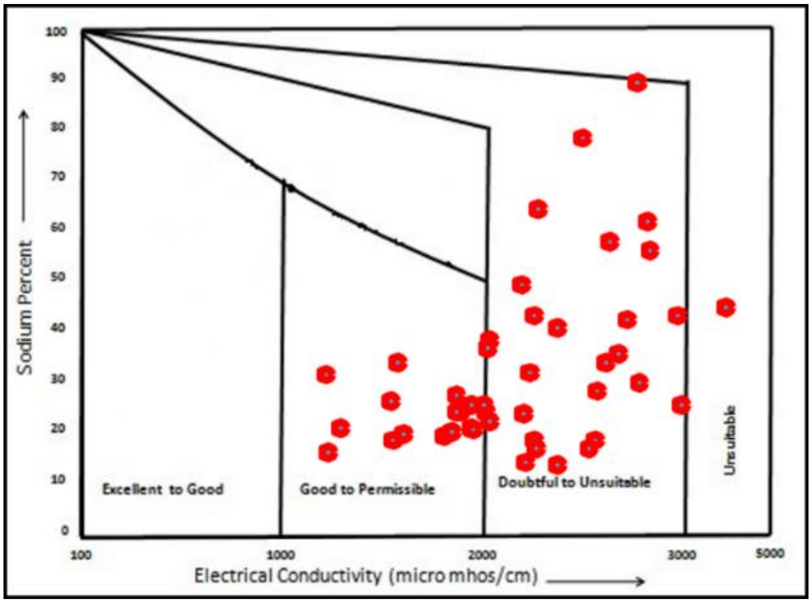



Figure 5.18(a) Wilcox plot for the irrigated waters of KHSB during pre-monsoon

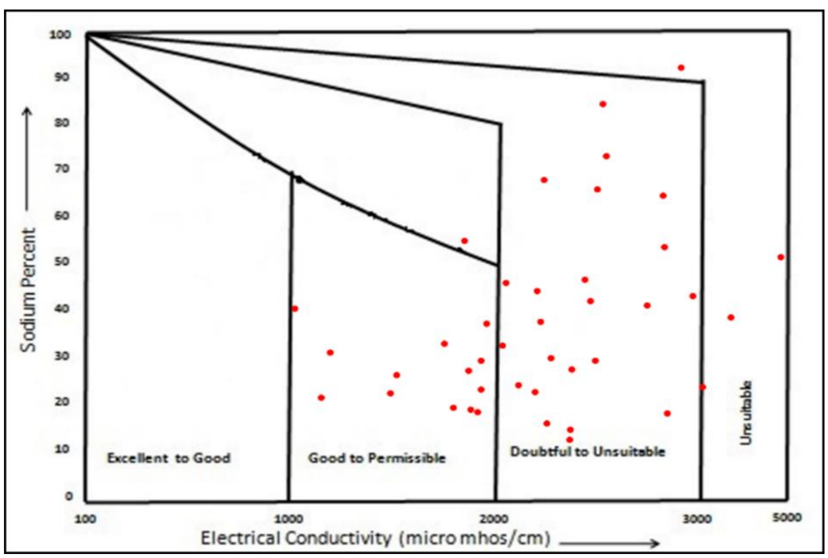



Figure 5.18(b) Wilcox plot for the irrigated waters of KHSB during Post Monsson

#### 5.3.2.5 Residual Sodium Carbonate (RSC)

Eaton (1950) introduced an index to check the alkalinity hazard in irrigated water which is referred as Residual Sodium Carbonate. Carbonates (CO3 + HCO3) in water when exceeds Ca and Mg, this increases the sodium content in the soil which makes the soil swell and hinders its infiltration (Kundu et al 2011). RSC is used as an index to evaluate the suitability of water for irrigation in clayey soil. Higher value of RSC in groundwater leads to alkali soil formation. Residual Sodium Carbonate is calculated using the formula 5.8.

$$RSC = (CO3 + HCO3) – (Ca = Mg) \quad (5.8)$$

Where all the values are epm

RSC values for present study were calculated for all the water samples during both season and classified (Table 5.5(a) and 5.5(b)). The study reveals that, 42 groundwater samples fall under the class- Good followed by 01 and 02 water samples under the class- Doubtful and Unsuitable respectively during pre-monsoon while 35 water samples fall under the class- Good followed by 02 and 04 samples fall under class- Doubtful and Unsuitable respectively during post-monsoon (Table 5.8 and 5.13).

Table 5.8 Classification based on RSC

| Limiting Value | Category | No. of samples during PRM | No. of samples during POM |
|---|---|---|---|
| <1.25 | Good | 42 | 35 |
| 1.25-2.50 | Doubtful | 1 | 2 |
| >2.50 | Unsuitable | 2 | 4 |

#### *5.3.2.6 Magnesium Hazard (MH)*

Calcium and magnesium are present in water in an equilibrium state but excess of magnesium in water has ill effect on the soil quality. Excessive Mg concentration in irrigated water damages the soil structure and affects the crop yield (Szacboles and Darab, 1964). This magnesium hazard (MH) is calculated by using the formula 5.9.

$$\mathrm{MH} = \left[\frac{\mathrm{Mg}}{\mathrm{Ca} + \mathrm{Mg}}\right] \mathrm{x}\ 100 \qquad (5.9)$$

Where all the values are epm

Table 5.9 Classification of MH for irrigation (Szacboles and Darab, 1964)

| MH | Class | No. of samples during PRM | No. of samples during POM |
|---|---|---|---|
| <50% | Suitable | 43 | 26 |
| >50% | Unsuitable | 02 | 15 |

MH values for the present study during PRM and POM are calculated and classified (Table 5.5(a) and 5.5(b)). From the classification, it is observed that, 43 groundwater samples fall under the class- Suitable and 02 water sample fall under the class- Unsuitable while during POM, 26 water samples are classed under Suitable and 15 water samples are classed under Unsuitable for irrigation (Table 5.9 and 5.13).

#### *5.3.2.7 Permeability Index (PI)*

Doneen (1964) introduced the term “Permeability index” to measure the degree of soil permeability. PI is mainly influenced by calcium, magnesium, sodium and bicarbonate concentration in the soil (Li et al 2014). Low PI values results in poor crop yield and doesn’t support better plant growth. PI values are computed using the formula 5.10.

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na}\ \mathrm{x}100 \qquad (5.10)$$

Where all the values are epm

Table 5.10 Classification based on PI values (after Doneen, 1964)

| PI range | Category | No. of samples during PRM | No. of samples during POM |
|---|---|---|---|
| <25% | Class-I | - | - |
| 25-75% | Class-II | 42 | 38 |
| >75% | Class-III | 03 | 03 |

Accordingly, the computed and classified PI value for present study is presented in Table 5.5(a) and Table 5.5.(b). The classification suggests that, all the water samples during both PRM and POM season are classed under Class-II indicating suitability of water for irrigation except 03 groundwater samples which falls under Class-III indicating unsuitability of water for irrigation both during PRM and POM season (Table 5.10 and 5.13).

#### ***5.3.2.8 Kelley's Ratio (KR)***

KR is the indication of high levels of Na against Ca and Mg in water. Kelley (1963) introduced this ratio to check its suitability of water for irrigation purpose. He suggested that KR value <1 is good for irrigation while KR>1 is unsuitable. Therefore, the KR is calculated using the formula 5.11.

$$\mathrm{KI} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}} \qquad (5.11)$$

Where all the values are epm

Based on the above, all the water samples of KHSB were calculated for KR and classified (Table 5.5(a) and 5.5(b)). The study shows that, 41 and 35 water samples are suitable for irrigation during PRM and POM respectively while 04 and 06 water samples are unsuitable for irrigation during PRM and POM respectively (Table 5.11 and 5.13).

Table 5.11 Classification based on Kelley Ratio (after Kelley, 1963)

| Kelley Ratio | No. of samples during PRM | No. of samples during POM |
|---|---|---|
| <1 | 41 | 35 |
| >1 | 04 | 06 |

### *5.3.2.9 Hydrochemical Classification (Piper, 1944)*

The composition of groundwater is best understood by the geochemical processes taking place within the groundwater system. In the present study, to determine the geochemical evolution of Kanavihalla Sub-basin, piper trilinear diagram was used. Piper (1944) diagram is used to classify the facies of subsurface and ground water based on its major ions. In piper diagram, there are two triangle fields of cations and anions and, third diamond shaped field. The hydrochemical data is plotted on triangular field which is on a scale of 0-100 parts. For the convenience of plotting the values of cations and anions are converted to epm from ppm. The plotting on the diamond field is obtained by the intersection points upwards from their respective plotting of cations and anions on the triangular fields. The diamond field is then used to classify water of different types. The different types of facies classification of water in the diamond field are: Ca-Mg-HCO3 type; Na-K-HCO3 type; Na-K-Cl-SO4 type; Ca-Mg-Cl-SO4 type. The main objective of the Piper diagram is to show the water samples of similar composition.

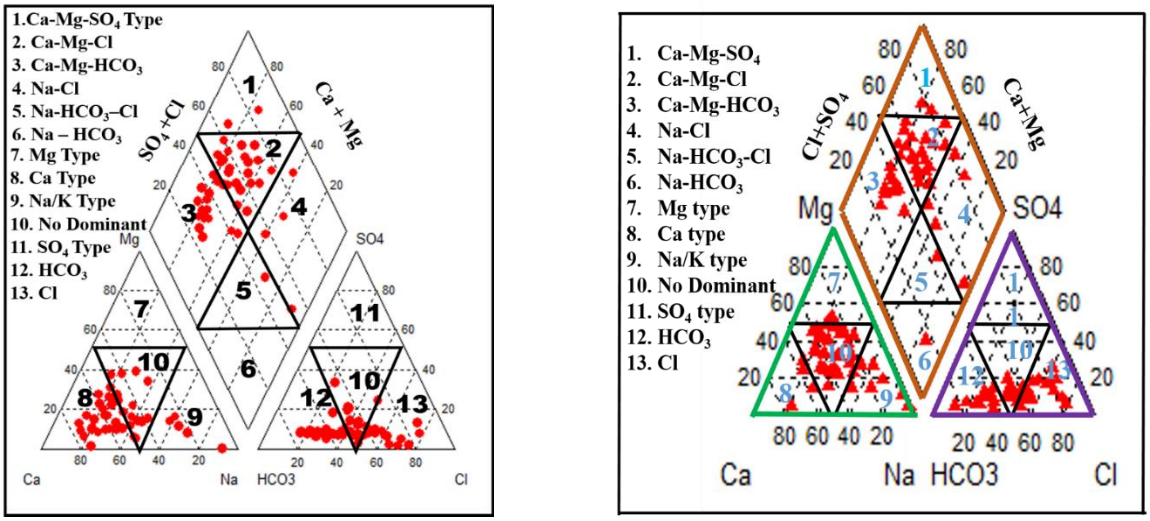



Figure 5.19 Geochemical relationship among the waters of KHSB during pre-monsoon and Post Monsson

Aquachem 3.70 software was used to plot the piper diagram of Kanavihalla Sub-basin. From the study it was observed that during PRM season (Figure 5.19(a)), the majority of the groundwater samples (48.88%) fall in the field Ca-Mg-Cl type followed by 35.55% of the water samples fall in the field Ca-Mg-HCO3 type while remaining- 8.88%, 4.44% and 2.22% of water sample fall in the field: Na-Cl type, Ca-Mg-SO4 type and Na-HCO3-Cl type respectively. Further, during POM season (Figure 5.19(b)), the variation in the plot is much alike as during PRM. The majority of the groundwater samples (48.77%) fall in the field Ca-Mg-Cl type followed by 31.70% of the water samples fall in the field Ca-Mg-HCO3 type while remaining- 12.19%, 4.87% and 2.43% of water sample fall in the field: Na-Cl type, Ca-Mg-SO4 type and Na-HCO3-Cl type respectively.

### *5.3.2.10 Factors controlling the groundwater chemistry*

The chemistry of groundwater is influenced by the interaction of rock and water due to some of the processes such as rock weathering, mineral dissolution, leaching, ion exchange and evaporation and also due to anthropogenic activities. Based on the above controlling factors, Gibbs (1970) classified the water as atmospheric precipitation, rock weathering and evaporation type. This study helps not only in establishing the relationship between composition of water and geology but also gives an insight into as which factors is controlling the groundwater chemistry.

Many researchers have tried to discuss the mechanism controlling water chemistry such as Conway (1942), Gorham (1961), Mackenzie and Garrels (1965) but most widely used is that of the Gibbs (1970). In Gibbs plot, the results of analysis of groundwater samples are plotted for the ratios, Na/Na+Ca against TDS and Cl/Cl+HCO3 against TDS. This graphical method of classification has been used by various researchers in their studies (Ghalib, 2017; Nag and Chowdhury, 2019; Panneerselvam et al 2020).

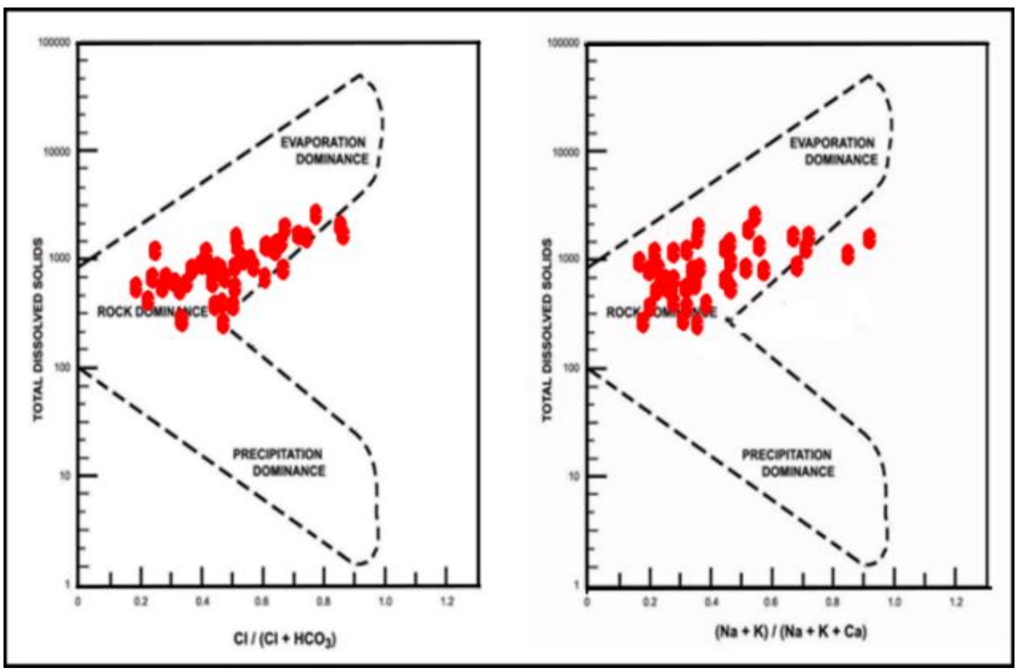



Figure 5.20(a) Mechanism controlling the chemistry of groundwater during pre-monsoon (After Gibbs, 1970)

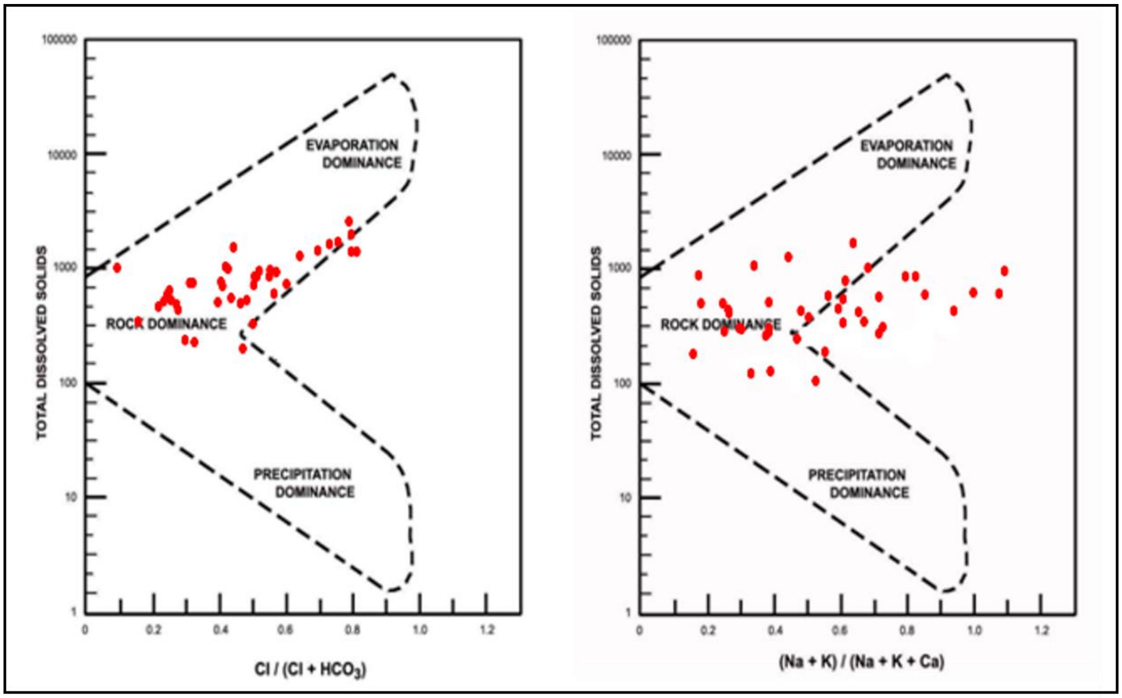



Figure 5.20(b) Mechanism controlling the chemistry of groundwater during Post Monsson (After Gibbs, 1970)

The above was plotted for water samples of Kanvihalla Sub-Basin using Aquachem software and from the plot (Figure 5.20(a) and 5.20(b)). It was observed that, all the groundwater samples during both the season fall in the field of Rock Dominance indicating the chemistry of groundwater is predominantly controlled by rock-water interaction.

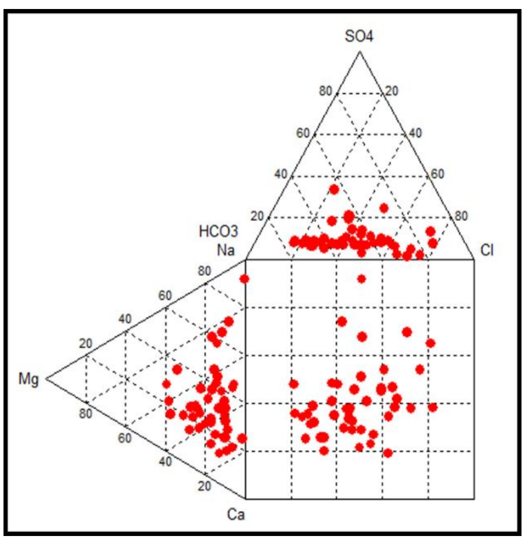
### *5.3.2.11 Durov Classification*

In this diagram, the concentration of major cations and anions are plotted on two separate triangles similar to that of trilinear diagram where the triangle on the left represents cations and the other triangle on the right represents anions and later projected on a single square field. The square field represents the overall chemical characteristics of the water samples.

The groundwater samples of both the season for the present study were plotted in Durov diagram using Aquachem software. From the study following observations were made. During pre-monsoon, 14 (31.5%) groundwater samples were found to be falling under No Contamination class while 29 (65%) water samples were found to be falling under class Moderate Quality followed by 02 (4.5%) water sample falling under class-High contamination of Na & Cl. While during post-monsoon, 19 (46.34%) groundwater samples were found to be falling under No Contamination class while 19 (46.34%) water samples were found to be falling under class Moderate Quality followed by 03 (7.5%) water sample falling under class- Pure Water (Figure 5.21(a) and 5.21(b) and Table 5.12).

Table 5.12 Durov's Classification for irrigated waters of KHSB

| **Field** | **Quality** | **No. of Samples during PRM** | **%** | **No. of samples during POM** | **%** |
|---|---|---|---|---|---|
| A | Pure Water | - | - | 03 | 7.5 |
| B | No Contamination | 14 | 31.5 | 19 | 46.34 |
| C | Moderate Quality | 29 | 65 | 19 | 46.34 |
| D | High contamination of Na & Cl | 02 | 4.5 | - | - |



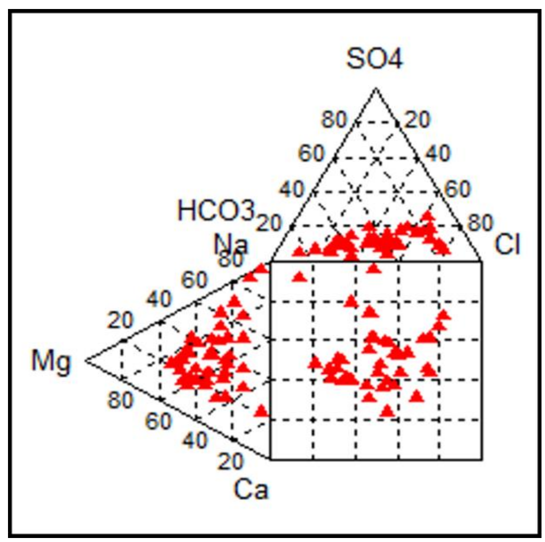




Figure 5.21 Durov diagram for pre-monsoon and post monsson water samples of KHSB

Table 5.13 Classification of groundwater quality for agricultural suitability (After Bouderbala, A. 2017, BIS 2012).

| **Classification pattern** | **Class** | **Ranges** | **Number of samples(PRM)** | **Number of samples(POM)** |
|---|---|---|---|---|
| EC (Wilcox 1955) | Excellent | < 250 | - | 0 |
| | Good | 250 – 750 | 7 | 5 |
| | Permissible | 750 – 2250 | 31 | 27 |
| | Doubtful | 2250 – 5000 | 7 | 9 |
| | Unsuitable | > 5000 | - | 0 |
| Chloride (meq/L) (Ayers & Westcot (1985) | Excellent | <4 | 21 | 17 |
| | Good | 4-7 | 10 | 11 |
| | Permissible | 7-12 | 7 | 6 |
| | Doubtful | 12-20 | 4 | 3 |
| | Unsuitable | > 20 | 3 | 4 |
| Sodium percentage (% Na) (Wilcox 1955) | Excellent | 0 - 20 | 8 | 3 |
| | Good | 20 - 40 | 25 | 19 |
| | Permissible | 40 - 60 | 8 | 13 |
| | Doubtful | 60 – 80 | 2 | 4 |
| | Unsuitable | > 80 | 2 | 2 |
| SAR (Richard 1954) | Very low | < 2 | 25 | 41 |
| | Low | 2 - 12 | 19 | - |
| | Medium | 12 - 22 | 1 | - |
| | High | 22 – 32 | - | - |
| | Very high | > 32 | - | - |
| PI (Doneen 1964) | Suitable | < 75 | 42 | 37 |
| | Unsuitable | ≥ 75 | 3 | 4 |
| RSC (meq/L) | Permissible | < 1.25 | 45 | 35 |
| | Unsuitable | ≥ 1.25 | - | 6 |
| MAR Raghunath (1987) | Permissible | 0-50 | 43 | 18 |
| | Unsuitable | >50 | 2 | 23 |
| Kelly's ratio Kelley (1940) | Suitable | <1 | 40 | 8 |
| | Unsuitable | ≥1 | 5 | 33 |
| Total dissolved Solids (TDS) mg/l | Good | <450 | 7 | 5 |
| | Permissible | 450-2000 | 37 | 33 |
| | Unsuitable | >2000 | 1 | 3 |

### 5.3.3 Data analysis using matrix

The descriptive statistics for groundwater samples is given in Table 5.2(a) and 5.2(b). According to the correlation matrix, "+1 or -1" are treated as high correlation coefficient value and which indicates a better relationship between the two variables. If the value is nearer to zero indicates no relationship between two variables at a significant level of $P < 0.05$ (Singh et al., 2011). If $r > 0.7$ and between 0.4 and 0.7 can be considered that the parameters are strongly correlated and moderately correlated respectively. Here correlation matrix is used to understand any association amid the experimentally observed parameters by which the factor loadings using PCA was discussed.

#### *5.3.3.1 Pearson Correlation Coefficients*

The detailed examination of the correlation matrix is advantageous as it shows the role of each parameter individually and their influence in the process of hydrochemistry (Helena et al., 2000; Khan, 2011). The Pearson correlation matrix is generated and presented (Table 5.14(a) and 5.14(b)). If the variables coefficient value (r) > 0.4 are considered as important.

In the PRM the pH has a negative correlation with the Ca2+, K+, NO3- and TH+, and positive correlation with other parameters whereas in POM negative correlation with the $Ca^{2+}$, $Mg^{2+}$, $Cl^-$ , $SO_4^{2-}$ and $TH^+$, and positive correlation with other parameters with $r < 0.4$, except $F^-$, which has a moderate correlation. In the PRM the EC has a strong correlation with the TDS, Ca2+, TH+, Cl-, Na+ and moderate correlation with $HCO_3^-$, $SO_4^{2-}$, $Mg^{2+}$ whereas in the POM it has a strong correlation with TDS, $Ca^{2+}$, $TH^+$, $Cl^-$, $Na^+$, $SO_4^{2-}$and moderate correlation with $HCO_3^-$ and $Mg^{2+}$ signifying that the maximum number of ions have participated in the process of physiochemical reactions like ion exchange and source for the ions might be the same (Subbu Rao, 2002). $Mg^{2+}$ -$TH^+$, $TH^+$-$Cl^-$, $Ca^{2+}$ - $TH^+$, $TH^+$-TDS, $Ca^{2+}$ -$Cl^-$, $Mg^{2+}$ - $Cl^-$, $Na^+$- Cl-, TDS- $Cl^-$, $Ca^{2+}$- TDS, TDS-$Na^+$ showed high correlation in both seasons whereas $Mg^{2+}$ - $Cl^-$ showed high correlation in PRM and TDS-$SO_4$, $Ca^{2+}$- $SO_4$, $Na^+$- $SO_4$, $Cl^-$- $SO_4$, TH- $SO_4$ and Alkalinity-$F^-$ showed high correlation in POM.

The moderate correlation can be observed between $Na^{+}$-$TH^{+}$, Alkalinity-$Na^{+}$, TDS-Alkalinity, $Mg^{2+}$-$SO_4^{2-}$, $Ca^{2+}$- $Mg^{2+}$, $Ca^{2+}$-$Na^{+}$, TDS-$Mg^{2+}$, SO42 -Fe in both seasons whereas moderate correlation is observed between $Mg^{2+}$ - $Cl^{-}$. Alkalinity –$NO_3$, in PRM and $HCO_3$-$TH^{+}$, $HCO_3$-Cl-, $HCO_3^{-}$ - $Ca_2^{+}$, $SO_4^{2}$-TDS, Fe-$Mg_2^{+}$, $Mg_2^{+}$ - $Na^{+}$ in POM.

Table 5.14(a) Correlation coefficient matrix(PRM)

| | **Ph** | **EC** | **TDS** | **Ca** | **Mg** | **Na** | **K** | **Fe** | **TH** | **HCO3** | **Cl** | **SO4** | **NO3** | **F** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1.000 | | | | | | | | | | | | | |
| **EC** | 0.060 | 1.000 | | | | | | | | | | | | |
| **TDS** | 0.060 | **1.000** | **1.000** | | | | | | | | | | | |
| **Ca** | -0.390 | **0.770** | **0.770** | 1.000 | | | | | | | | | | |
| **Mg** | -0.300 | **0.570** | **0.570** | **0.570** | 1.000 | | | | | | | | | |
| **Na** | 0.270 | **0.780** | **0.780** | **0.400** | 0.280 | 1.000 | | | | | | | | |
| **K** | 0.220 | 0.040 | 0.040 | -0.110 | -0.170 | -0.030 | 1.000 | | | | | | | |
| **Fe** | -0.060 | 0.020 | 0.020 | 0.020 | 0.040 | 0.050 | 0.030 | 1.000 | | | | | | |
| **TH** | -0.400 | **0.770** | **0.770** | **0.940** | **0.820** | **0.400** | -0.150 | 0.030 | 1.000 | | | | | |
| **HCO3** | **0.480** | **0.460** | **0.460** | -0.010 | 0.220 | **0.670** | 0.150 | 0.000 | 0.090 | 1.000 | | | | |
| **Cl** | -0.160 | **0.830** | **0.830** | **0.730** | **0.590** | **0.780** | 0.040 | 0.030 | **0.760** | 0.280 | 1.000 | | | |
| **SO4** | -0.030 | **0.930** | **0.930** | **0.810** | **0.550** | **0.700** | 0.010 | 0.080 | **0.800** | 0.260 | **0.810** | 1.000 | | |
| **NO3** | 0.300 | 0.090 | 0.090 | -0.100 | 0.050 | 0.230 | 0.030 | -0.090 | -0.050 | **0.440** | 0.010 | -0.050 | 1.000 | |
| **F** | **0.580** | 0.110 | 0.110 | -0.320 | -0.140 | 0.380 | -0.140 | -0.110 | -0.280 | **0.710** | -0.140 | -0.070 | 0.380 | 1.000 |

Table 5.14(b) Correlation coefficient matrix(POM)

| | **pH** | **EC** | **TH** | **$HCO_3$** | **Cl** | **$SO_4$** | **Ca** | **Mg** | **Na** | **K** | **$NO_3$** | **F** | **Fe** | **TDS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1.000 | | | | | | | | | | | | | |
| **EC** | 0.197 | 1.000 | | | | | | | | | | | | |
| **TH** | -0.115 | **0.769** | 1.000 | | | | | | | | | | | |
| **$HCO_3$** | 0.307 | **0.695** | **0.433** | 1.000 | | | | | | | | | | |
| **Cl** | 0.054 | **0.914** | **0.837** | **0.514** | 1.000 | | | | | | | | | |
| **$SO_4$** | 0.177 | **0.408** | 0.349 | 0.027 | 0.390 | 1.000 | | | | | | | | |
| **Ca** | -0.205 | **0.715** | **0.968** | **0.422** | **0.785** | 0.238 | 1.000 | | | | | | | |
| **Mg** | 0.131 | **0.685** | **0.800** | 0.340 | **0.731** | **0.519** | **0.625** | 1.000 | | | | | | |
| **Na** | 0.285 | **0.844** | **0.503** | **0.688** | **0.820** | 0.294 | **0.462** | **0.464** | 1.000 | | | | | |
| **K** | -0.074 | 0.230 | 0.019 | 0.331 | 0.123 | -0.073 | 0.035 | -0.023 | 0.036 | 1.000 | | | | |
| **$NO_3$** | -0.043 | 0.272 | 0.272 | 0.243 | 0.182 | 0.142 | 0.241 | 0.271 | 0.099 | 0.127 | 1.000 | | | |
| **F** | **0.554** | 0.283 | -0.037 | 0.352 | 0.036 | 0.111 | -0.118 | 0.168 | 0.204 | -0.036 | 0.266 | 1.000 | | |
| **Fe** | 0.205 | 0.060 | 0.100 | -0.119 | 0.070 | **0.512** | -0.053 | **0.438** | -0.021 | -0.196 | 0.088 | 0.128 | 1.000 | |
| **TDS** | 0.197 | **1.000** | **0.769** | **0.695** | **0.914** | **0.409** | **0.715** | **0.685** | **0.844** | 0.230 | 0.272 | 0.283 | 0.060 | 1.000 |

In general, the concentration of Cl- is low in the crystalline terrains (Karanth, 1987). The Concentration of Cl- in the water may become high due to the leaching of the saline residues from the soil, but the influence of routine anthropogenic activities and climatic conditions may also be a reason for Cl- concentration. The Positive correlation between Na+ and Cl- is high and indicates that there is a possibility of the confluence of two groundwater bodies which are having a different end-member composition like fresh and saline (Datta and Tyagi, 1996; Rao, 2002). The High correlation between $Na^{+}$- $Cl^{-}$, TDS-$Cl^{-}$ and moderate correlation of $Mg^{2+}$ - $Cl^{-}$ shows the effect of agronomic activity in the KHSB. The presence of magnesium calcareous material in KHSB is indicated by the correlation between $Mg^{2+}$ -$SO_4^{2-}$.

The correlation matrix is also interpreted easily using scatter matrix plot along with pictorial representation (Figure 5.22(a) and 5.22(b)) From the figures 5.22(a) and 5.22(b) it clearly shows that $K^{+}$ is neither correlating with any other parameter nor varying with the other parameter. Figures 5.22(a) and 5.22(b) are the replication of the Table 5.14(a) and 5.14(b) respectively to understand the correlation easily. To check the adequacy of the data for statistical analysis the KMO and Bartlett's test is conducted and sampling adequacy is 0.64 which is greater than the value given by the test (0.5)**.**

### *5.3.3.2 Factor Analysis*

The factor analysis is an important method where the large set of data with numerous variables can be reduced into a fewer number of factors. This technique also identifies the structure between the variables and their relationship along with variables. The vital feature of this technique is to extract the PC which are in linear groupings with all variables and which can illustrate the maximum of the total variance.

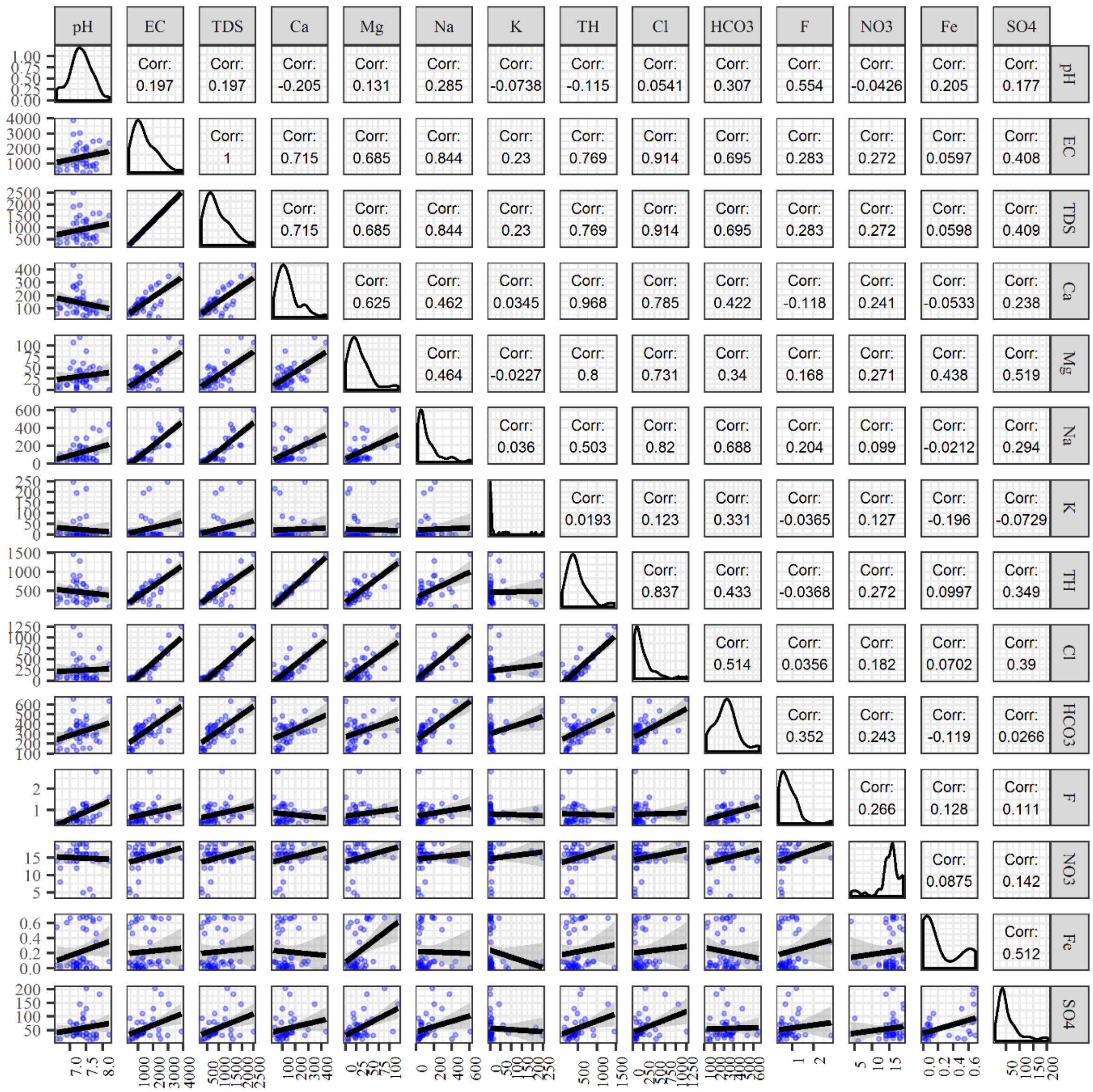



Figure.5.22(a) Scatter matrix plot(PRM)

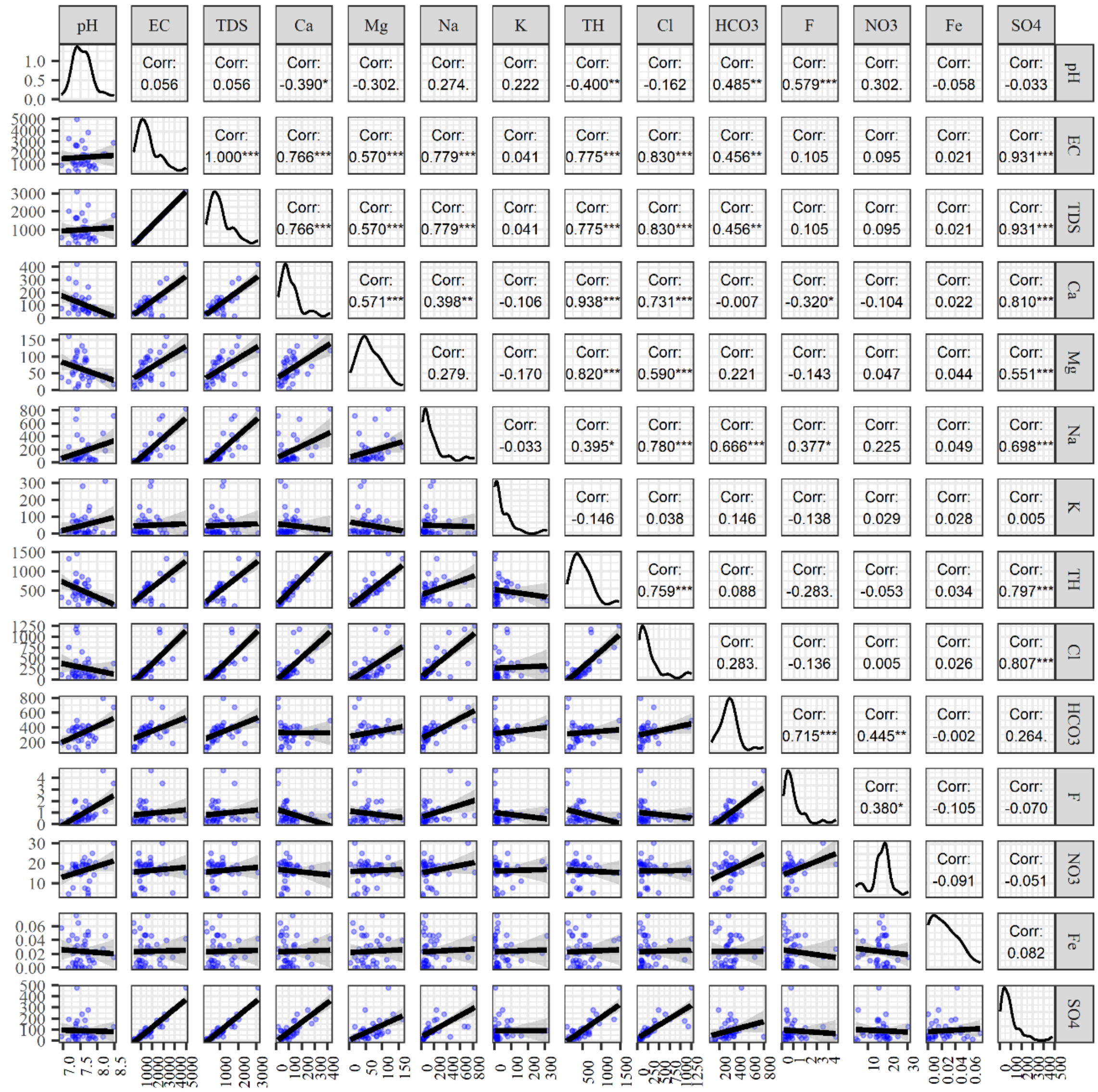



Figure 5.22(b) Scatter matrix plot(POM)

Table 5.15 Total Variance Explained

| Factor | Initial Eigen Values(PRM) | | | Initial Eigen Values(POM) | | |
|---|---|---|---|---|---|---|
| | **Eigen Value** | **% of variance** | **Cumulative %** | **Eigen Value** | **% of variance** | **Cumulative %** |
| 1 | 6.341 | 45.293 | 45.293 | 6.279 | 44.851 | 44.851 |
| 2 | 1.977 | 14.123 | 59.416 | 3.022 | 21.587 | 66.437 |
| 3 | 1.812 | 12.943 | 72.359 | 1.201 | 8.577 | 75.014 |
| 4 | 1.110 | 7.928 | 80.287 | 0.992 | 7.087 | 82.101 |
| 5 | 0.891 | 6.366 | 86.653 | 0.849 | 6.065 | 88.166 |
| 6 | 0.537 | 3.836 | 90.490 | 0.555 | 3.966 | 92.132 |
| 7 | 0.436 | 3.111 | 93.601 | 0.451 | 3.219 | 95.351 |
| 8 | 0.357 | 2.550 | 96.151 | 0.336 | 2.402 | 97.753 |
| 9 | 0.286 | 2.041 | 98.193 | 0.134 | 0.957 | 98.711 |
| 10 | 0.184 | 1.313 | 99.506 | 0.109 | 0.782 | 99.492 |
| 11 | 0.051 | 0.363 | 99.869 | 0.059 | 0.419 | 99.911 |
| 12 | 0.018 | 0.131 | 100.000 | 0.012 | 0.089 | 100.000 |
| 13 | 2.770E-07 | 1.979E-06 | 100.000 | 0.000 | 0.000 | 100.000 |
| 14 | 1.376E-07 | 9.825E-07 | 100.000 | 0.000 | 0.000 | 100.000 |

| | **Extraction sums of squared loadings** | | **Extraction sums of squared loadings** | | |
|---|---|---|---|---|---|
| **Total** | **% of variance** | **Cumulative %** | **Total** | **% of Variance** | **Cumulative %** |
| 6.341 | 45.293 | 45.293 | 6.279 | 44.851 | 44.851 |
| 1.977 | 14.123 | 59.416 | 3.022 | 21.587 | 66.437 |
| 1.812 | 12.943 | 72.359 | 1.201 | 8.577 | 75.014 |
| 1.110 | 7.928 | 80.287 | | | |

The maximum residual variability is defined by the remaining factors (Behera, & Das, 2018). The factors which are extracted are orthogonal to each other. Eigenvalues are the variances that are extracted from the factors. Therefore, the factors with eigenvalues which are greater than 1 are only selected. Correlations of the original variables in the factors extracted are itself factor loadings. Four factors and scree plot (Figure 5.23(a) and 5.23(b)) are used to describe the 80.28% of total variances for PRM and three factors and scree plot (Figure 5.24 (a) and 5.24(b)) are used to describe the 75.01% of total variances in POM which are enough for obtaining correlation matrix.

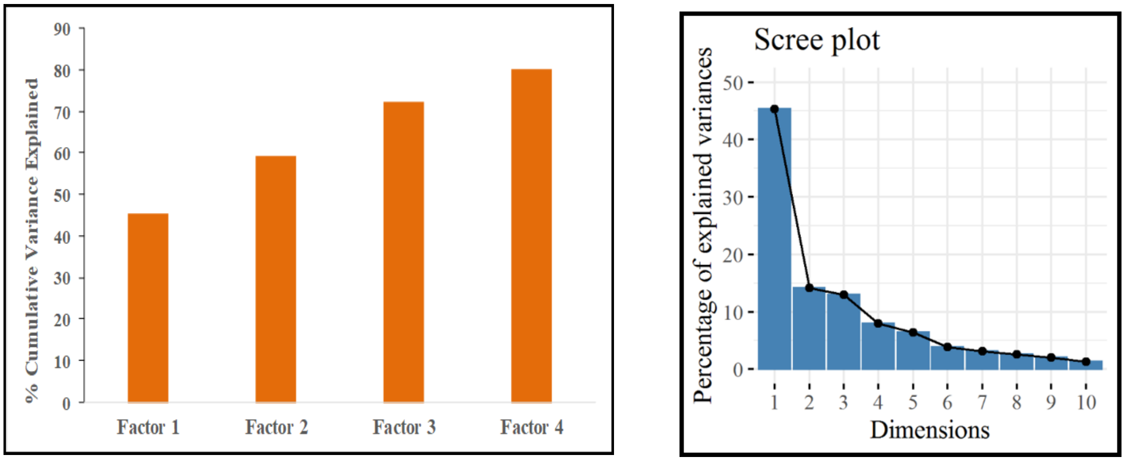



**Figure 5.23 a. Percentage of cumulative variance explained using PCA(PRM)**
**b. Scree plot graph(PRM)**

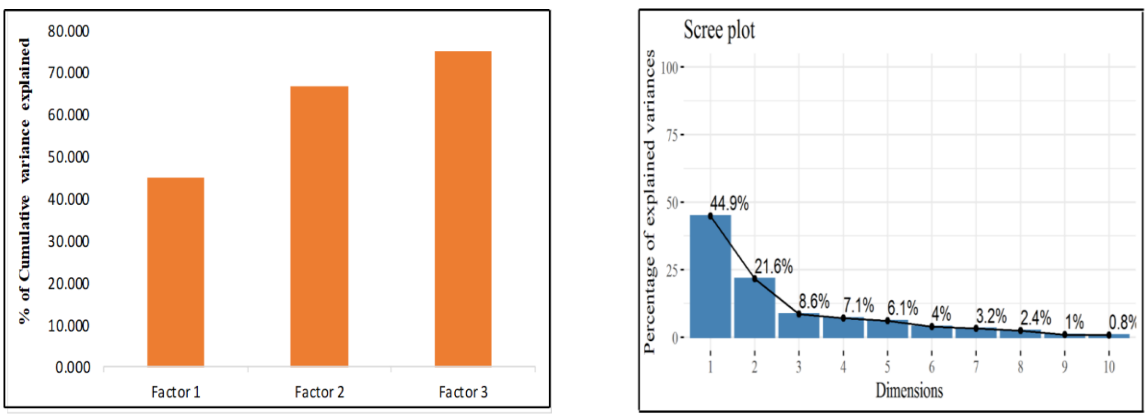



**Figure 5.24 a. Percentage of cumulative variance explained using PCA(POM)**
**b. Scree plot graph(POM)**

In the PC which was obtained initially, Eigenvalues and their percentage (%) of variance contributed to each PC is represented in Table 5.15. Figure 5.23(b) and 5.24(b) shows the scree plots for Eigenvalue for each component, where four and three PC are achieved which are having Eigen value greater than 1, together makes 80.28% and 75.01% of total variance using the set of water quality data for PRM and POM respectively. From the Figure 5.23(b) and 5.24(b) it is observed that there is a noticeable variation of the slope next to 4$^{th}$ and 3$^{rd}$ Eigen value for PRM and POM respectively (Cattell and Jaspers, 1967).

The first four components extracted for PRM and the three components for POM are of utmost significance, accounting for over 80.28% and 75% variance, respectively, in KHSB's groundwater. These significant components are discerned through Eigenvalues. Leveraging these four and three components for PRM and POM, respectively, the cumulative variance is described as follows: 45.29%, 14.12%, 12.94%, and 7.92% explained by PC 1 through PC 4 for PRM, and 44.85%, 21.58%, and 8.57% by PC 1 through PC 3 for POM.

Consideration of the component loadings is to understand the closeness amongst the variables and PC. Usually, the dominant loading with negative or positive values defines the meaning of the dimensions. In negative loading, with the increase in loading in dimensions, the contribution of the variables decreases and for positive loading, it is vice versa (Lawrence and Upchurch, 1982).

Table 5.16 Component matrix

| | **PRM** | | | | **POM** | | |
|---|---|---|---|---|---|---|---|
| | **Factor 1** | **Factor 2** | **Factor 3** | **Factor 4** | **Factor 1** | **Factor 2** | **Factor 3** |
| **pH** | 0.174 | 0.819 | -0.183 | -0.232 | -0.108 | 0.806 | 0.223 |
| **EC** | 0.970 | 0.029 | -0.140 | -0.040 | 0.962 | 0.149 | 0.086 |
| **TH** | 0.866 | -0.340 | 0.223 | 0.034 | 0.886 | -0.370 | -0.142 |
| **$HCO_3$** | 0.679 | -0.148 | -0.549 | 0.029 | 0.392 | 0.809 | -0.045 |
| **Cl** | 0.937 | -0.170 | 0.034 | -0.157 | 0.905 | -0.054 | 0.105 |
| **$SO_4$** | 0.465 | 0.292 | 0.572 | 0.032 | 0.935 | -0.034 | 0.140 |
| **Ca** | 0.794 | -0.471 | 0.120 | 0.008 | 0.846 | -0.392 | -0.027 |
| **Mg** | 0.798 | 0.067 | 0.408 | 0.086 | 0.701 | -0.229 | -0.293 |
| **Na** | 0.808 | 0.121 | -0.246 | -0.335 | 0.754 | 0.494 | 0.046 |
| **K** | 0.150 | -0.172 | -0.506 | 0.411 | -0.039 | 0.158 | 0.842 |
| **NO3** | 0.325 | 0.073 | -0.012 | 0.824 | 0.064 | 0.560 | -0.280 |
| **F** | 0.233 | 0.754 | -0.257 | 0.203 | -0.015 | 0.858 | -0.298 |
| **Fe** | 0.146 | 0.457 | 0.704 | 0.132 | 0.049 | -0.094 | 0.344 |
| **TDS** | 0.970 | 0.030 | -0.140 | -0.039 | 0.962 | 0.149 | 0.086 |

Observations indicate that in the PRM's first factor (Figure 5.25(a) and 2.25(b)), EC, TDS, and Cl exhibit notably high loadings. Similarly, in the POM's primary factor, EC, TDS, Cl, and SO4 demonstrate considerably high loadings. Meanwhile, TH, HCO3, Ca, Mg, and Na display moderate to high loadings consistently across both seasons in both PRM and POM. This implies EC and TDS in the KHSB are primarily due to Na and Cl, although $HCO_3$ also plays a considerable part in determining TDS and EC. This shows the role of rainfall and wastewater from domestic uses, those are rich in $Na^+$, $Mg^{2+}$, and Cl- (Yidana, et al., 2008). Overall in factor 1, higher positive loadings are by EC, TH, Cl, $SO_4$, Ca, Mg, Na, and TDS (Table 5.16).

Since it has hydro geochemical variables like Cl, $SO_4$, Mg, Na, K, and EC seems to be originated by mineralization of the geological components of soil at first glimpse. But Na and Mg indicate the cation exchange processes at the soil-water interface (Guo and Wang, 2004). Few clay minerals like montmorillonite have high competences for the process of base exchange. Therefore, base exchange reactions might be present while dealing with water having variable quantities of Ca, Na and Mg. Limestone and andesite have the ability to produce the $Mg^{2+}$ concentration in the subsurface to some extent. Higher $Mg^{2+}$ may indicate the existence of granite and limestone in the area. Even alteration of mafic minerals/rocks with $Mg^{2+}$ composition may also contribute to the concentration of $Mg^{2+}$. The area is having quartzite derived from the granite which can be considered as one of the important influencing lithology for increasing concentration of $Mg^{2+}$ in groundwater (Singh et al., 2011).

The second factor (Figure 5.25(a) and 5.25(b)) is chiefly linked with high loadings by pH, Fe and F in PRM and by pH, Alkalinity and F in POM. The high positive loading of Fe is possible because of the dissolution of the lithogenic or non-lithogenic resources through seeping water. Also, rock-water interaction might be one of the causes for high loading of Fe when quartzite is associated with the ferruginous material. The minerals such as silicates, fluorite, fluorapatite, and also volcanic ash when dissolved results in increasing concentration of fluoride in groundwater (Hem, 1985). Usually, fluorite occurs in sedimentary, volcanic and plutonic rocks. It is also present in rocks such as granite, gneiss, and pegmatite (Rama Rao, 1982; Heinrich, 1948). Thus, weathering of such rocks leaches out fluoride (Singh, et al., 2011). This shows that the unmixing or partial mixing of different types of water by the domination of single variables in each factor. The high loading of pH probably infers that it may be caused by the origin from organic or biogenic sources (Reghunath, et al., 2002). Usually $HCO_3$ loading is linked up with the silicate weathering and which plays a vital role in order to supply the ions to the groundwater (Ahmad et al. 2019).

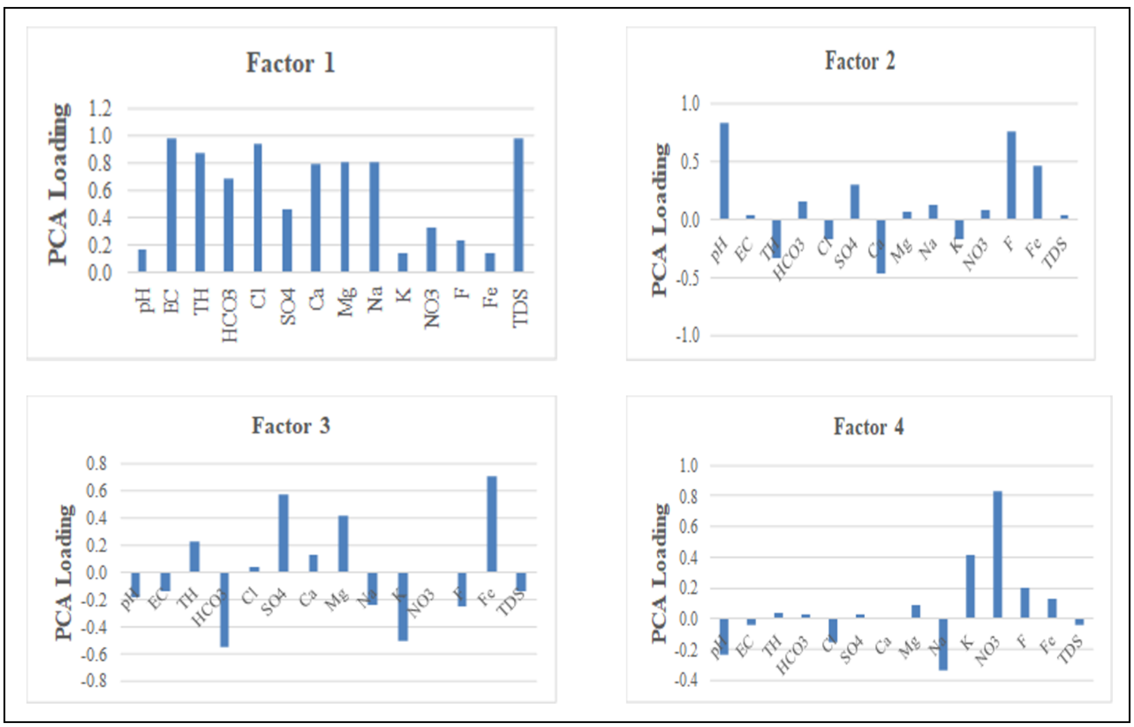



Figure.5.25(a) PCA loading for various factors (PRM)

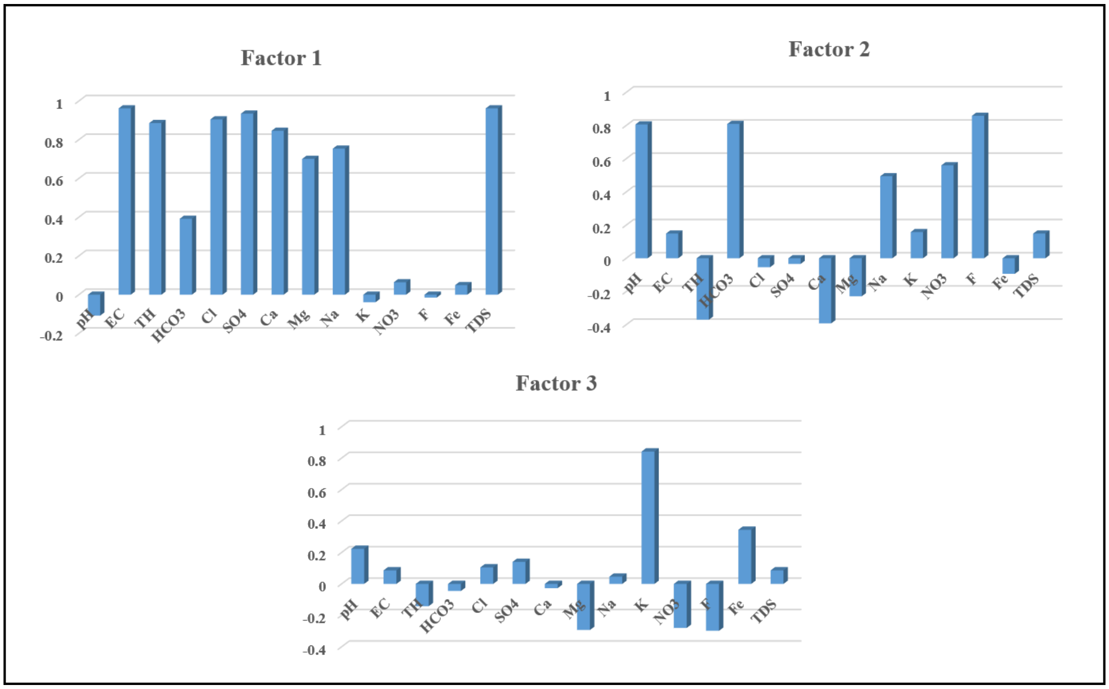



Figure 5.25(b). PCA loading for various factors (POM)

From the factor 3 (Figure 5.25(a)) for the PRM it is observed that $SO_4$, Fe and Mg show higher loading and the reason behind this loading is same as the factor 1 and 2 and for the POM (Figure 5.25(b)) it is observed that only potassium shows higher loading and the reason behind this loading is may be the influence of agricultural activity. Hence, agricultural activities are one reason behind the high content of K in groundwater (Ahmad et al. 2019).

Factor 4 in PRM (Figures 5.25(a)) contributes 7.92 % of the total variance. Higher loading of $NO_3$ clearly shows the source as agricultural activities which contains fertilizers, animal waste, organic matter etc. Agricultural sources affected by septic tanks and industrial effluents may also be the cause for increasing concentration of $NO_3$.

The loadings and scores plots of the first two PCs which explained a total of 59% in PRM and in POM 66.44% of variance are presented in figure 5.26(a)(b) and 5.26(c) and (d) respectively. The loadings plot shows grouping and relationship between the variables. The group of hydro-geochemical variables and their close relation is visible in the first quadrant of the loading plot. Such a grouping pattern signifies strength of their mutual relation. Overlapping of the samples may be due to almost similar hydro-geo-chemical conditions in the region (Farnham et al. 2003).

The present examination mainly aids to get the information on datasets regarding the causes of ion as well as the factors governing in groundwater quality (Islam et al., 2018). It can be summarized that extracted PC denotes four dissimilar processes that are accountable for a number of component loadings such as:

a. Geological processes like weathering and dissolution of minerals.
b. Fertilizers and other organic matter from agricultural activities.
c. Industrial discharges where the source is non-agricultural.
d. Rainfall and domestic wastewaters.

In general, loadings >0.6 may be considered for interpretation or the variables which are having high loading are considered as they are significant for assessment of the components (Mahloch, 1974).

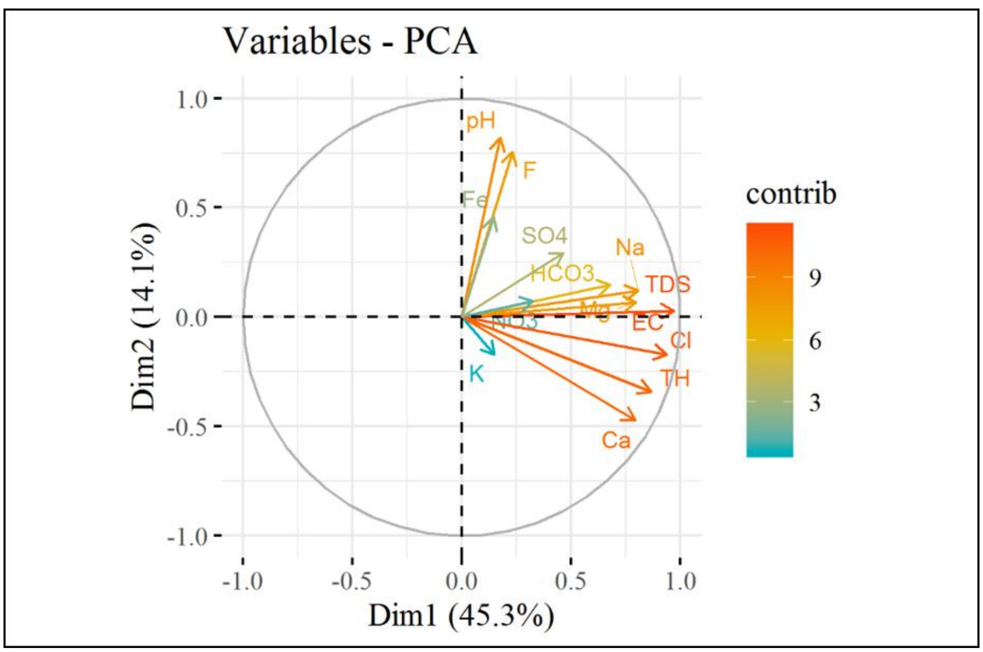



Figure 5.26(a) Loadings for the first two factors(PRM)

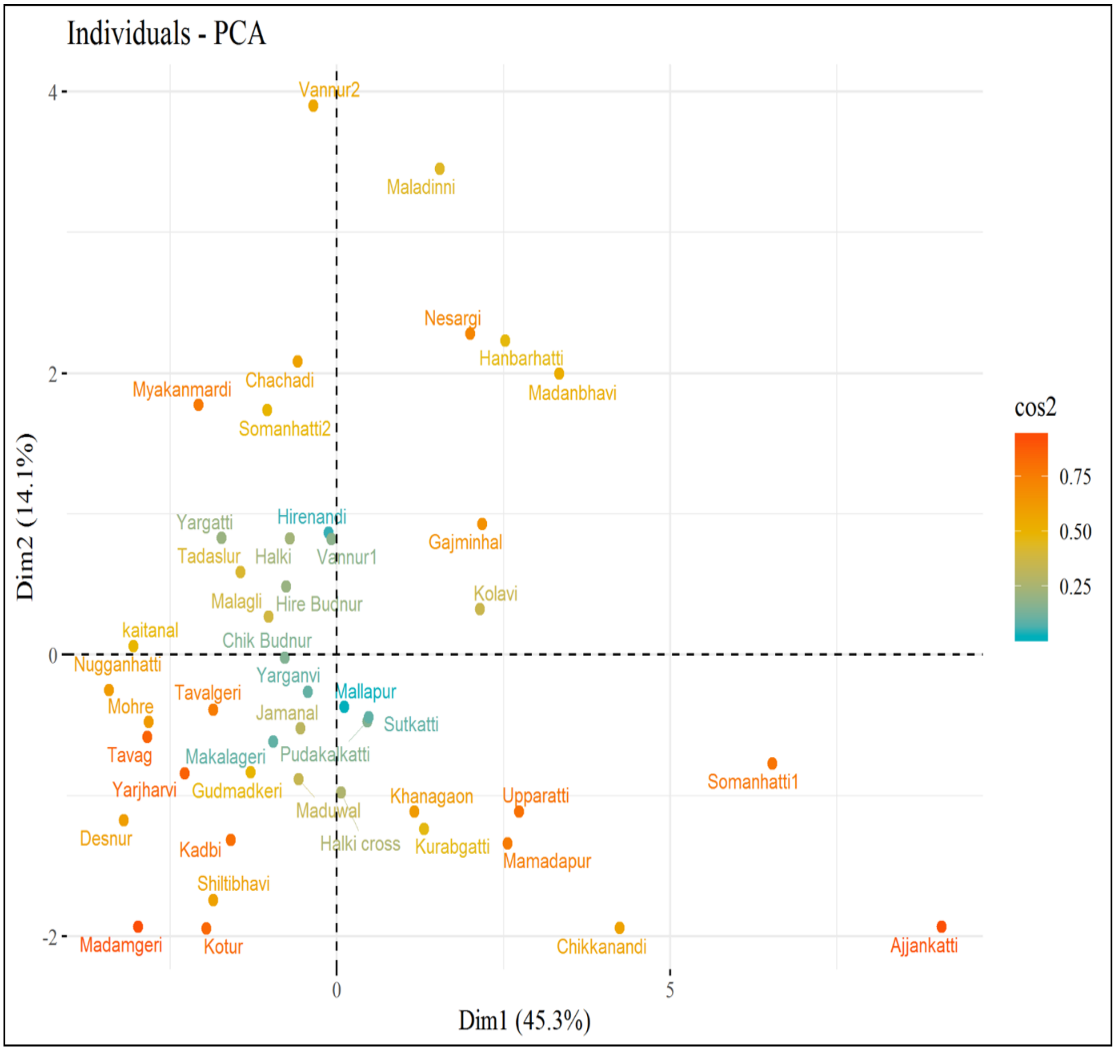



Figure 5.26(b) Score Plots for the first two factors(PRM)

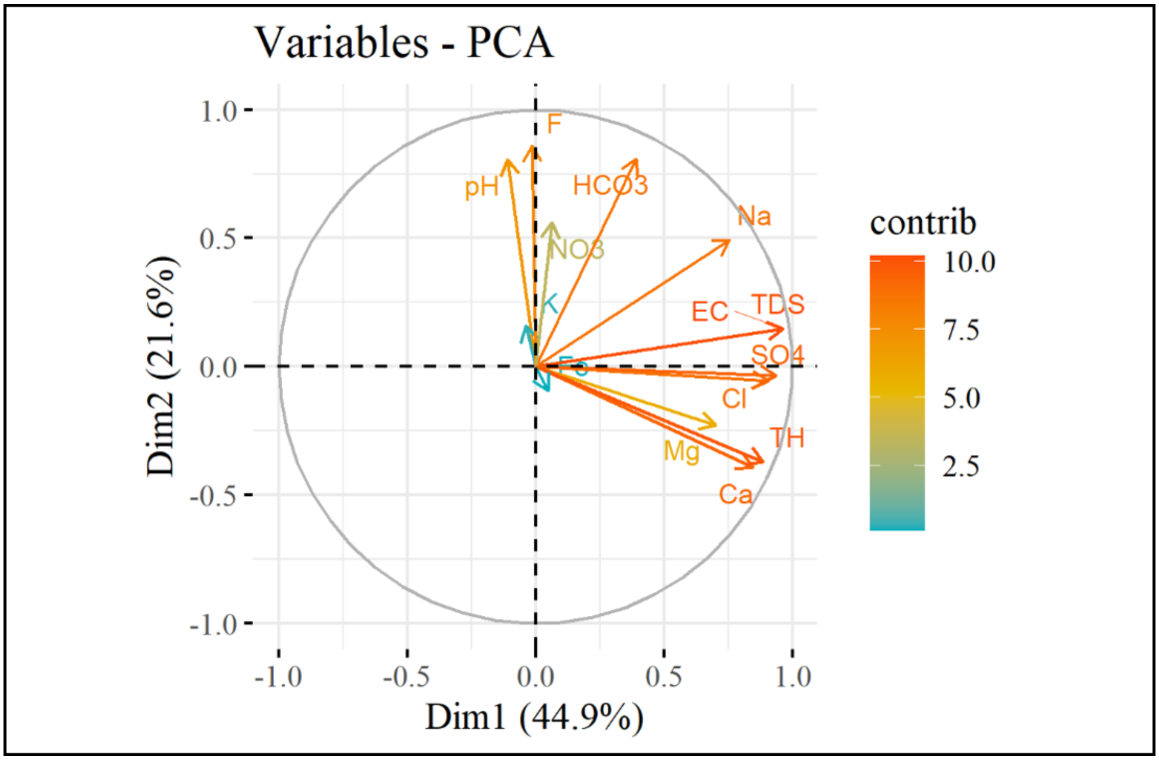



Figure 5.26(c) Loadings for the first two factors(POM)

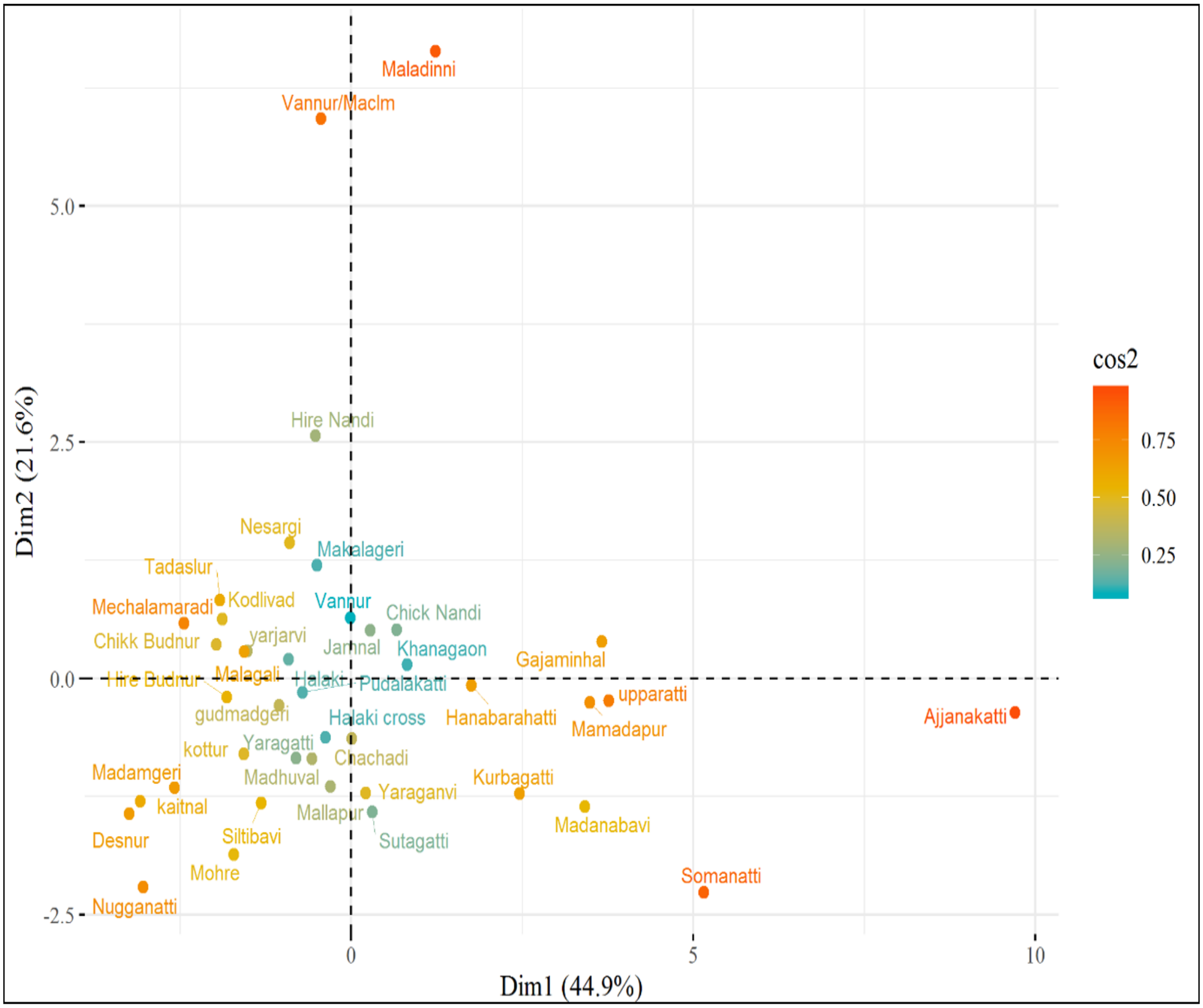



Figure 5.26(d) Score Plots for the first two factors(POM)

The analysis in terms of rotation mode delivers many positive features that make a better interpretation of the data set. Meanwhile, factor scores are also calculated for all samples which reveal the significance of a given factor at that sample location (Table 5.17). The Intensity of the chemical process in the groundwater quality is defined by each factor and can be correlated to obtained factor scores (Dalton and Upchurch, 1978).

Extreme negative and positive numbers (<-1 and > +1) reveals the area is totally unaffected and mostly affected respectively whereas, near to zero value depicts approximate area affected to an average degree by means of the chemical process of that particular factor (Senthilkumar et al., 2008). Hence the area is moderately affected by the chemical process as the scores are near to zero value.

Table 5.17 Component score covariance matrix

| | PRM | | | | POM | | |
|---|---|---|---|---|---|---|---|
| | **Factor 1** | **Factor 2** | **Factor 3** | **Factor 4** | **Factor 1** | **Factor 2** | **Factor 3** |
| **pH** | -0.014 | 0.436 | 0.048 | -0.184 | -0.046 | 0.245 | 0.210 |
| **EC** | 0.156 | 0.071 | -0.040 | 0.006 | 0.147 | 0.059 | 0.077 |
| **TH** | 0.152 | -0.186 | 0.074 | 0.037 | 0.153 | -0.095 | -0.127 |
| **$HCO_3$** | 0.104 | 0.203 | -0.222 | 0.092 | 0.033 | 0.275 | -0.012 |
| **Cl** | 0.186 | -0.050 | -0.005 | -0.113 | 0.145 | -0.010 | 0.087 |
| **$SO_4$** | 0.008 | 0.016 | 0.357 | -0.008 | 0.149 | -0.006 | 0.116 |
| **Ca** | 0.164 | -0.222 | -0.007 | 0.021 | 0.148 | -0.112 | -0.033 |
| **Mg** | 0.080 | -0.047 | 0.247 | 0.063 | 0.119 | -0.041 | -0.248 |
| **Na** | 0.178 | 0.156 | -0.110 | -0.248 | 0.102 | 0.171 | 0.053 |
| **K** | -0.010 | 0.004 | -0.239 | 0.407 | -0.011 | -0.013 | 0.705 |
| **$NO_3$** | -0.104 | -0.023 | 0.100 | 0.730 | -0.010 | 0.205 | -0.214 |
| **F** | -0.072 | 0.389 | 0.044 | 0.204 | -0.033 | 0.303 | -0.222 |
| **Fe** | -0.081 | 0.046 | 0.455 | 0.058 | 0.011 | -0.057 | 0.280 |
| **TDS** | 0.156 | 0.071 | -0.040 | 0.006 | 0.147 | 0.059 | 0.077 |

### 5.3.4 Saturation index(SI)

Saturation index is the measure of state of equilibrium when the rock-water interacts. The ability of a mineral to dissolve in aqueous solution largely depends on the process of disintegration and decomposition of rock masses and minerals to the soil (Venturelli et al, 2003; Chidambaram et al 2011). The changes in saturation state are helpful in identifying various stages of hydrochemical evolution and the parameters controlling the chemistry of water (Drever, 1997; Langmuir, 1997; Coetsiers and Walraevens, 2006; Aghazadeh et al 2016). Generally, the SI values less than zero indicate that the groundwater is Under-Saturated; the SI value of zero indicates that the groundwater is in equilibrium while SI value greater than zero indicates that the groundwater is Over-Saturated.

Saturation indices were derived for the mineral phase in water from the hydro-chemical modelling, shows that the groundwater points are saturated with reference to calcite, dolomite, aragonite except in few points and undersaturated with reference to halite anhydrite, gypsum, fluorite. The SI was calculated for halite, calcite, dolomite, anhydrite, gypsum and aragonite of ground water samples from the KHSB for both PRM and POM season and in the PRM these were ranged between -7.64 to -4.81, -0.88 to 1.62, -2.43 to 2.09, -2.96 to -0.96, -2.47 to -0.74, -1.02 to 1.47 respectively and in POM -7.52 to -4.68, -0.48 to 1.07, -1.08 to 2.17, -5.97 to -0.93, -3.1 to -0.71, and -0.63 to 0.93 (Table 11). The SI values of halite, anhydrite and gypsum that are shown with a negative sign indicates the undersaturated state, while those of calcite, dolomite and aragonite ranged from saturated to undersaturated are shown with both negative and positive signs. The SI values of the water samples of KHSB were calculated for both season using WEB-PHREEQ aqueous geochemical modeling and are presented in Table 5.18(a) & Table 5.18(b). Instability among the dissolution - precipitation states were clearly revealed by the SI values of aragonite, calcite and dolomite; but absolute tendency to remain in dissolution conditions in groundwater was showed by SI values of halite, anhydrite and gypsum (Abboud, 2018). The unsaturated condition of halite, anhydrite and gypsum was due to the decrease in the quantity of dissolved Ca with increase in the precipitation of aragonite, calcite and dolomite in groundwater. Halite is under unsaturated state and may also be due to the ion exchange process in between Ca and Na. The decrease in the quantity of Ca in groundwater may also due to the process of ion exchange or dissolution of halite, anhydrite and gypsum that might be caused by the saturation of calcite, aragonite and dolomite (Abboud, 2018).

Table 5.18(a) Saturation indices for various minerals(PRM)

| Sample | Saturation indices of minerals(PRM) | | | | | |
|---|---|---|---|---|---|---|
| | **Anhydrite** | **Aragonite** | **Calcite** | **Dolomite** | **Gypsum** | **Halite** |
| KHSB 1 | -2.96 | 0.18 | 0.33 | -0.11 | -2.47 | -7.64 |
| KHSB 2 | -2.37 | -0.33 | -0.19 | -0.56 | -2.15 | -7.06 |
| KHSB 3 | -2.12 | -0.05 | 0.09 | -0.53 | -1.9 | -7 |
| KHSB 4 | -1.98 | -0.53 | -0.39 | -1.54 | -1.76 | -6.75 |
| KHSB 5 | -2.44 | -0.64 | -0.49 | -1.92 | -2.22 | -7.18 |
| KHSB 6 | -1.94 | 0.41 | 0.56 | -0.42 | -1.72 | -6.94 |
| KHSB 7 | -1.67 | 0.4 | 0.55 | 0.47 | -1.46 | -6.41 |
| KHSB 8 | -2.12 | 0.12 | 0.27 | -0.15 | -1.9 | -7.12 |
| KHSB 9 | -2.35 | 0.17 | 0.31 | 0.33 | -2.13 | -6.14 |
| KHSB 10 | -2.12 | 0.54 | 0.68 | 1.08 | -1.9 | -5.54 |
| KHSB 11 | -1.66 | 0.58 | 0.73 | 0.69 | -1.44 | -5.51 |
| KHSB 12 | -1.8 | 0.59 | 0.73 | 0.97 | -1.59 | -5.63 |
| KHSB 13 | -2.79 | 0.83 | 0.98 | 0.75 | -2.57 | -5.4 |
| KHSB 14 | -2.25 | 0.1 | 0.24 | -0.33 | -2.03 | -6.5 |
| KHSB 15 | -1.91 | 0.52 | 0.66 | 0.75 | -1.7 | -6.05 |
| KHSB 16 | -2.13 | -0.5 | -0.35 | -1.18 | -1.91 | -6.31 |
| KHSB 17 | -2.08 | 0 | 0.14 | -0.07 | -1.86 | -6.14 |
| KHSB 18 | -1.69 | 0.44 | 0.58 | 0.53 | -1.47 | -5.96 |
| KHSB 19 | -1.99 | -0.24 | -0.1 | -0.27 | -1.77 | -7.56 |
| KHSB 20 | -2.17 | 0.15 | 0.29 | 0.48 | -1.95 | -6.32 |
| KHSB 21 | -2.11 | -0.37 | -0.23 | -1.07 | -1.89 | -7.12 |
| KHSB 22 | -2.54 | 0.72 | 0.86 | 1.54 | -2.32 | -5.3 |
| KHSB 23 | -1.9 | 0.74 | 0.88 | 1.52 | -1.68 | -4.81 |
| KHSB 24 | -2 | 0.32 | 0.47 | 0.43 | -1.78 | -6.57 |
| KHSB 25 | -2.28 | 0.43 | 0.57 | 0.98 | -2.06 | -6.82 |
| KHSB 26 | -2.02 | 0.4 | 0.54 | 0.81 | -1.8 | -6.61 |
| KHSB 27 | -2.36 | 0.45 | 0.59 | 0.86 | -2.14 | -7.11 |
| KHSB 28 | -2.1 | 0.57 | 0.71 | 1.02 | -1.88 | -6.91 |
| KHSB 29 | -2.17 | 0.79 | 0.93 | 1.55 | -1.95 | -6.31 |
| KHSB 30 | -2.19 | 0.47 | 0.62 | 0.88 | -1.97 | -6.46 |
| KHSB 31 | -1.57 | 0.46 | 0.61 | 0.58 | -1.35 | -6.42 |
| KHSB 32 | -2.42 | 0.5 | 0.64 | 1.33 | -2.2 | -7.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| KHSB 33 | -2.52 | 0.49 | 0.63 | 1.09 | -2.3 | -7.45 |
| KHSB 34 | -1.78 | 0.5 | 0.65 | 1.27 | -1.56 | -5.7 |
| KHSB 35 | -1.7 | 0.59 | 0.73 | 1 | -1.48 | -6.54 |
| KHSB 36 | -2.58 | -1.02 | -0.88 | -2.43 | -2.36 | -7.28 |
| KHSB 37 | -2.17 | -0.68 | -0.54 | -1.47 | -1.95 | -7.28 |
| KHSB 38 | -1.75 | 0.1 | 0.24 | 0.31 | -1.53 | -6.71 |
| KHSB 39 | -1.55 | 0.35 | 0.49 | 1.19 | -1.33 | -5.91 |
| KHSB 40 | -1.71 | 0.6 | 0.74 | 1.33 | -1.49 | -5.83 |
| KHSB 41 | -0.96 | 1.47 | 1.62 | 2.09 | -0.74 | -5.27 |
| KHSB 42 | -1.42 | 0.59 | 0.74 | 1.36 | -1.2 | -5.34 |
| KHSB 43 | -2.46 | 0.39 | 0.53 | 1.28 | -2.24 | -7.09 |
| KHSB 44 | -1.95 | 0.5 | 0.65 | 1.41 | -1.73 | -6.89 |
| KHSB 45 | -2.2 | 0.68 | 0.82 | 1.41 | -1.98 | -7.17 |

Table 5.18(b) Saturation indices for various minerals(POM)

| **Sample No** | **Saturation indices of minerals (POM)** | | | | | |
|---|---|---|---|---|---|---|
| | **Anhydrite** | **Aragonite** | **Calcite** | **Dolomite** | **Gypsum** | **Halite** |
| KHSB 1 | -3.32 | -0.55 | -0.41 | -0.67 | -3.1 | -7.52 |
| KHSB 2 | -2.56 | 0.23 | 0.37 | 0.95 | -2.34 | -7.06 |
| KHSB 3 | -2.06 | 0.36 | 0.5 | 0.53 | -1.84 | -6.56 |
| KHSB 4 | -2.67 | 0 | 0.14 | -0.76 | -2.45 | -7.06 |
| KHSB 5 | -2.23 | 0.29 | 0.43 | 1.26 | -2.01 | -6.74 |
| KHSB 6 | -1.37 | 0.57 | 0.71 | 1.19 | -1.15 | -5.97 |
| KHSB 7 | -5.97 | 0.66 | 0.8 | 1.65 | -2.05 | -7.02 |
| KHSB 8 | -2.37 | 0.71 | 0.85 | 2.17 | -2.15 | -5.98 |
| KHSB 9 | -1.77 | 0.93 | 1.07 | 2.06 | -1.55 | -5.72 |
| KHSB 10 | -1.68 | 0.39 | 0.53 | 1.34 | -1.46 | -4.99 |
| KHSB 11 | -1.47 | 0.59 | 0.74 | 1.74 | -1.25 | -5.3 |
| KHSB 12 | -2.7 | 0.69 | 0.83 | 2.12 | -2.48 | -5.21 |
| KHSB 13 | -2.07 | 0.42 | 0.56 | 1.18 | -1.85 | -6.1 |
| KHSB 14 | -2.04 | 0.5 | 0.64 | 1.44 | -1.82 | -6.02 |
| KHSB 15 | -2.25 | -0.04 | 0.1 | 0.36 | -2.03 | -6.25 |
| KHSB 16 | -2.09 | 0.53 | 0.68 | 1.73 | -1.87 | -5.92 |
| KHSB 17 | -2 | 0.5 | 0.64 | 1.68 | -1.78 | -5.93 |
| KHSB 18 | -2.7 | 0 | 0.15 | 0.16 | -2.48 | -7.42 |

| | | | | | | |
|---|---|---|---|---|---|---|
| KHSB 19 | -1.72 | 0.32 | 0.46 | 0.81 | -1.5 | -6.22 |
| KHSB 20 | -0.93 | 0.85 | 1 | 1.8 | -0.71 | -4.68 |
| KHSB 21 | -2.02 | 0.36 | 0.5 | 1.2 | -1.8 | -6.46 |
| KHSB 22 | -2.39 | 0.09 | 0.24 | 0.92 | -2.17 | -6.74 |
| KHSB 23 | -2.26 | 0.3 | 0.45 | 1.13 | -2.04 | -6.7 |
| KHSB 24 | -2.7 | 0.44 | 0.58 | 1.51 | -2.48 | -7.16 |
| KHSB 25 | -2.3 | 0.33 | 0.47 | 1.16 | -2.08 | -6.94 |
| KHSB 26 | -2.29 | 0.6 | 0.74 | 1.52 | -2.07 | -6.92 |
| KHSB 27 | -2.29 | 0.56 | 0.71 | 1.36 | -2.07 | -6.73 |
| KHSB 28 | -1.93 | 0.46 | 0.6 | 1.65 | -1.71 | -6.27 |
| KHSB 29 | -3.14 | 0.54 | 0.68 | 2.06 | -2.92 | -6.16 |
| KHSB 30 | -2.89 | 0.41 | 0.56 | 1.58 | -2.67 | -7.46 |
| KHSB 31 | -2.28 | 0.26 | 0.41 | 1.18 | -2.06 | -6.04 |
| KHSB 32 | -1.98 | 0.35 | 0.5 | 1.24 | -1.76 | -6.45 |
| KHSB 33 | -2.98 | -0.63 | -0.48 | -1.08 | -2.76 | -7.29 |
| KHSB 34 | -2.27 | -0.39 | -0.25 | -0.46 | -2.05 | -6.73 |
| KHSB 35 | -1.82 | 0.41 | 0.55 | 0.97 | -1.6 | -6.63 |
| KHSB 36 | -1.55 | 0.55 | 0.69 | 1.53 | -1.33 | -5.73 |
| KHSB 37 | -1.7 | 0.5 | 0.64 | 1.27 | -1.49 | -4.77 |
| KHSB 38 | -1.17 | 0.63 | 0.77 | 1.18 | -0.95 | -5.58 |
| KHSB 39 | -1.36 | 0.47 | 0.61 | 1.3 | -1.14 | -5.41 |
| KHSB 40 | -1.76 | 0.36 | 0.5 | 1.04 | -1.54 | -6.35 |
| KHSB 41 | -2.2 | 0.24 | 0.38 | 1.3 | -1.99 | -6.16 |

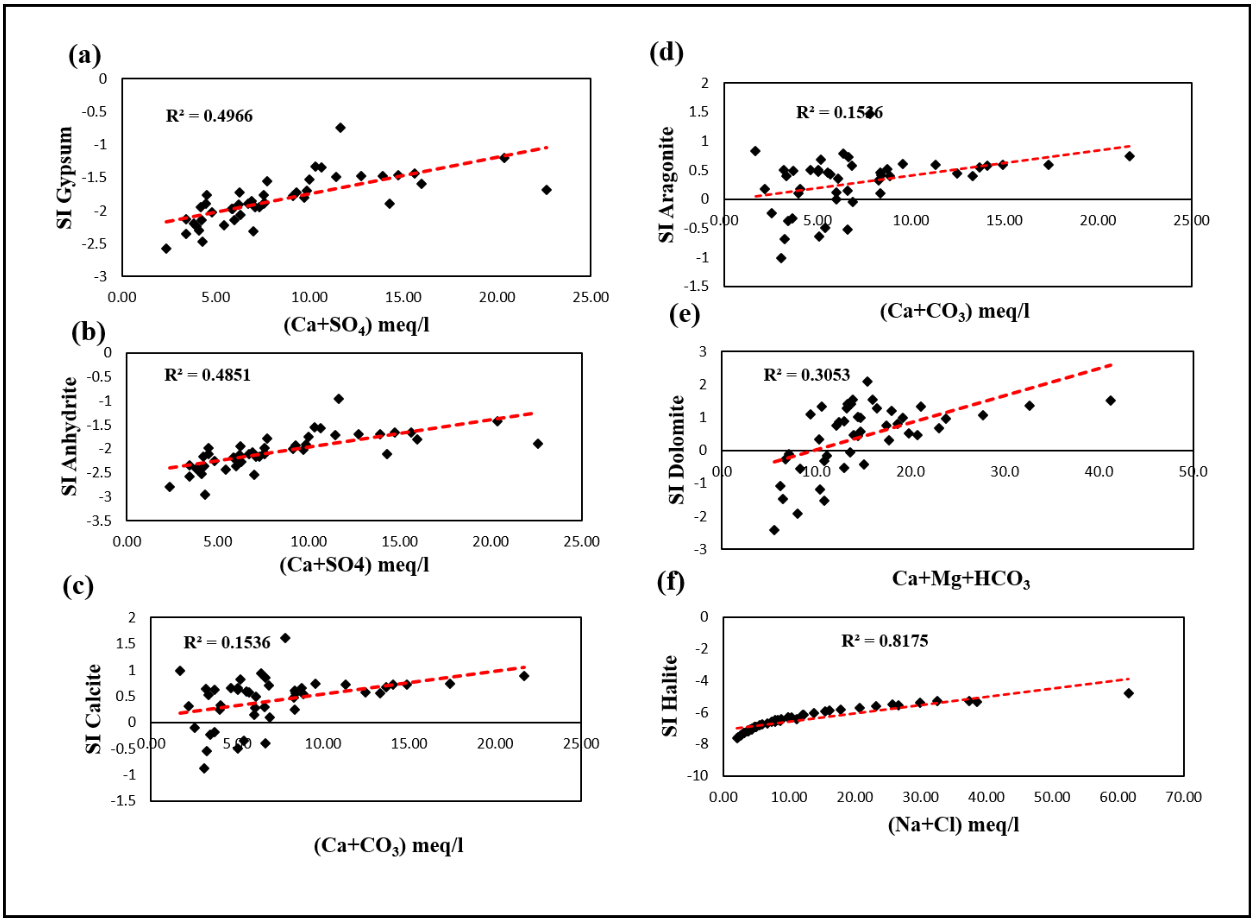



Figure 5.27 SI Plots (PRM) (a) SI gypsum vs $Ca+SO_4$ (b) SI anhydrite vs $Ca+SO_4$ (c) SI Calcite VS $Ca+CO_3$ (d) SI aragonite vs $Ca+CO_3$ (e) SI dolomite vs $Ca+Mg+HCO_3$ (f) SI Halite vs Na+Cl

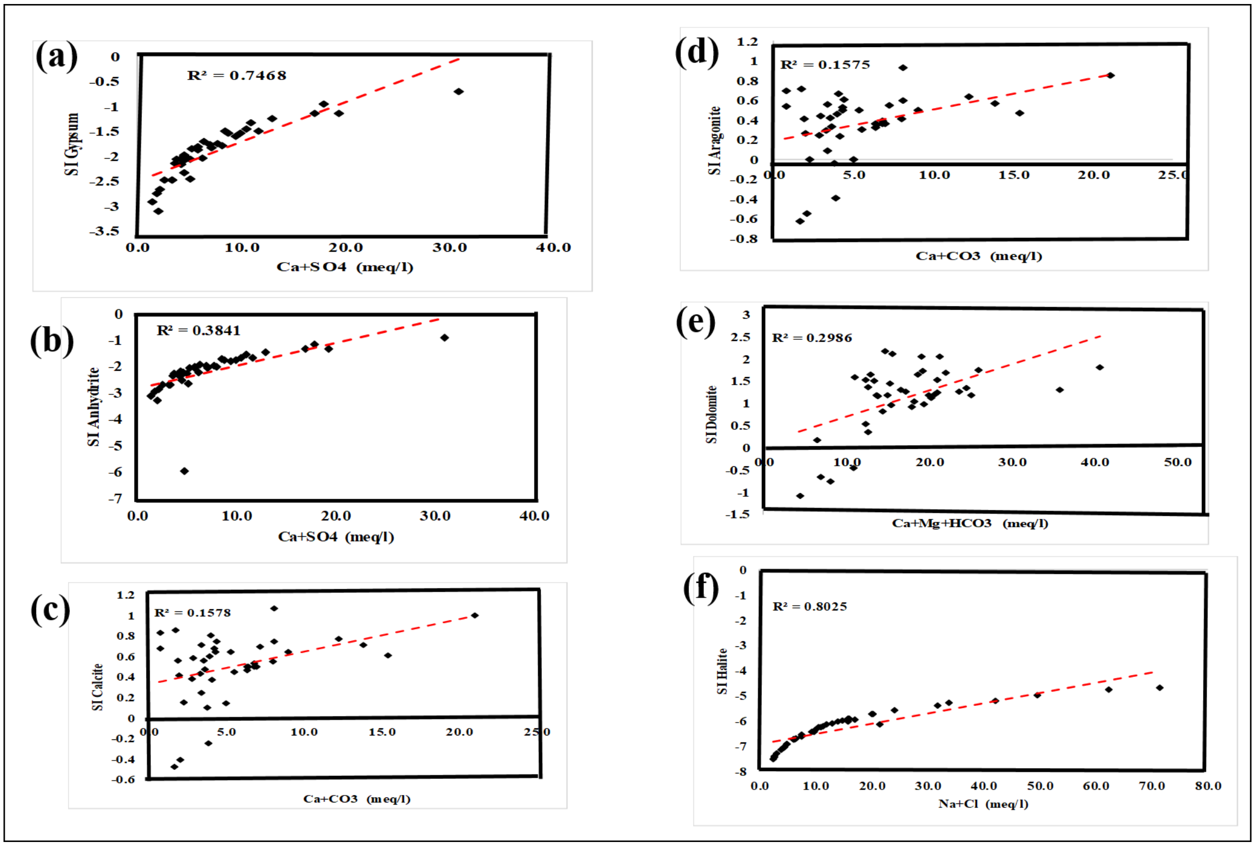



Figure 5.28 SI Plots (POM) (a) SI gypsum vs Ca+$SO_4$ (b) SI anhydrite vs Ca+$SO_4$ (c) SI Calcite VS Ca+$CO_3$ (d) SI aragonite vs Ca+$CO_3$ (e) SI dolomite vs Ca+Mg+$HCO_3$ (f) SI Halite vs Na+Cl

The SI value of halite showed undersaturation which may cause the dissolution of sulfate and carbonate minerals that influences the production of high $Ca^{2+}$ and $Mg^{2+}$ concentration in groundwater (El Alfy et al., 2017). The process of dissolution can also be highlighted by the relative parabolic relationship between the SI of halite and the sum of Na and Cl, which also exhibits the excess chloride originated from several sources since many points are located under 1:1 halite dissolution line (Figure. 5.27(f) and 5.28(f)). Since, SI value for few samples showed highly undersaturated depict, which is not the only source of sodium and chloride, instead they may also have originated by the source of contamination from the surface. The gypsum and anhydrite showed negative SI for all the samples (Figure 5.27(a &b) and 5.28(a & b)) that confirms the dissolution of sulphate minerals. Hence, the deficiency of Ca and Na related to cation exchange process (Kammoun et al., 2018). So, oversaturation and equilibrium states (SI>0 and SI=0 respectively) showed by both calcite and dolomite may be the cause for inability to dissolve in the groundwater (Figure 5.27 (d & e) and 5.28 (d & e)). Therefore, calcium seems to be chiefly derived either from dissolution of evaporates (gypsum and anhydrite) or by cation exchange reaction and fertilizers (Kammoun et al., 2018).

### 5.3.5 Water quality index

The analytical results of WQI have been assessed to check the groundwater for anthropogenic consumption by comparing with the disclaimers set by the Indian Standards (2012). Classification of groundwater into five classes based on the WQI values (Table 5.19) and type of groundwater for each groundwater sample is given (Table 5.20(a) and 5.20(b)).

Table 5.19 According to the WQI type of water (Sahu and Sikdar 2008)

| **Range of WQI** | **No. of Samples (PRM)** | **% of WQI in each class (PRM)** | **No. of Samples (POM)** | **% of WQI in each class (POM)** | **Type of water** |
|---|---|---|---|---|---|
| < 50 | Nil | | 2 | 4.87 | Excellent water |
| 50.1 – 100 | 12 | 26.66 | 6 | 14.63 | Good water |
| 100.1 – 200 | 22 | 48.88 | 20 | 48.78 | Poor water |
| 200.1– 300 | 08 | 17.77 | 6 | 14.63 | Very poor water |
| >300 | 03 | 6.66 | 7 | 17.07 | Water unsuitable for drinking |

In the current analysis, the computed WQI values range from 51.17 to 435.21 for PRM and from 48.17 to 544.76 for POM. Accordingly, these values categorize the water into five classifications, ranging from "excellent water" to "water unsuitable for drinking" (Rabeiy, 2018). Notably, two samples fall within the excellent category in POM, while around 49% of the samples are classified as "poor water." Furthermore, approximately

26.66% and 14.63% of the samples represent good water in PRM and POM, respectively. Moreover, 17.77% and 14.63% of the samples are categorized as very poor water in PRM and POM, and 6.66% and 17.07% of the samples in PRM and POM respectively fall into the "water unsuitable for drinking" category.

A map illustrating the spatial distribution of different water classes based on WQI has been generated (Figure 5.29(a) and 5.29(b)). In the case of PRM, a substantial portion of KHSB is encompassed by "poor water," covering approximately 456.61 km². Meanwhile, the areas occupied by good water, very poor water, and water deemed unsuitable for drinking measure around 111.64 km², 109.14 km², and 9.2 km², respectively. Similarly, for POM, a majority of the KHSB area is dominated by "poor water," encompassing nearly 467.64 km². Within this region, the areas occupied by excellent water, good water, very poor water, and water classified as unsuitable for drinking cover approximately 0.096 km², 29.34 km², 136.10 km², and 53.48 km², respectively.

Table 5.20(a) Calculation of WQI for individual water samples (PRM)

| **Sl No** | **Groundwater Sample** | **Source of groundwater collected** | **Name of the location** | **WQI value** | **Classification** |
|---|---|---|---|---|---|
| 1 | KHSB 1 | BW | Nugganhatti | 51.17 | Good water |
| 2 | KHSB 2 | BW | Yarjharvi | 84.56 | Good water |
| 3 | KHSB 3 | BW | Kadbi | 92.80 | Good water |
| 4 | KHSB 4 | BW | Kotur | 91.12 | Good water |
| 5 | KHSB 5 | HP | Madamgeri | 64.15 | Good water |
| 6 | KHSB 6 | BW | Gudmadkeri | 101.74 | Poor Water |
| 7 | KHSB 7 | HP | Kurabgatti | 181.72 | Poor Water |
| 8 | KHSB 8 | BW | Tavalgeri | 85.13 | Good water |
| 9 | KHSB 9 | HP | Hirenandi | 189.58 | Poor Water |
| 10 | KHSB 10 | HP | Chikkanandi | 312.06 | Water unsuitable for drinking |
| 11 | KHSB 11 | HP | Mamadapur | 232.08 | Very Poor Water |
| 12 | KHSB 12 | HP | Upparatti | 234.24 | Very Poor Water |
| 13 | KHSB 13 | HP | Maladinni | 239.23 | Very Poor Water |
| 14 | KHSB 14 | HP | Makalageri | 148.60 | Poor Water |
| 15 | KHSB 15 | HP | Pudakalkatti | 165.14 | Poor Water |

| | | | | | |
|---|---|---|---|---|---|
| 16 | KHSB 16 | BW | Shiltibhavi | 105.81 | Poor Water |
| 17 | KHSB 17 | BW | Jamanal | 138.04 | Poor Water |
| 18 | KHSB 18 | BW | Khanagaon | 182.28 | Poor Water |
| 19 | KHSB 19 | HP | Kaitanal | 57.98 | Good water |
| 20 | KHSB 20 | HP | Maduwal | 125.16 | Poor Water |
| 21 | KHSB 21 | BW | Tavag | 67.42 | Good water |
| 22 | KHSB 22 | HP | Kolavi | 251.27 | Very Poor Water |
| 23 | KHSB 23 | BW | Ajjankatti | 435.21 | Water unsuitable for drinking |
| 24 | KHSB 24 | HP | Yarganvi | 129.28 | Poor Water |
| 25 | KHSB 25 | BW | Halki | 111.89 | Poor Water |
| 26 | KHSB 26 | HP | Halki cross | 128.52 | Poor Water |
| 27 | KHSB 27 | HP | Tadaslur | 90.73 | Good water |
| 28 | KHSB 28 | HP | Malagli | 104.62 | Poor Water |
| 29 | KHSB 29 | HP | Hire Budnur | 116.41 | Poor Water |
| 30 | KHSB 30 | HP | Chik Budnur | 132.13 | Poor Water |
| 31 | KHSB 31 | HP | Vannur | 140.21 | Poor Water |
| 32 | KHSB 32 | HP | Vannur | 154.03 | Poor Water |
| 33 | KHSB 33 | HP | Myakanmardi | 85.54 | Good water |
| 34 | KHSB 34 | HP | Nesargi | 222.85 | Very Poor Water |
| 35 | KHSB 35 | HP | Sutkatti | 155.85 | Poor Water |
| 36 | KHSB 36 | BW | Desnur | 67.09 | Good water |
| 37 | KHSB 37 | BW | Mohre | 78.98 | Good water |
| 38 | KHSB 38 | BW | Mallapur | 142.24 | Poor Water |
| 39 | KHSB 39 | HP | Hanbarhatti | 227.46 | Very Poor Water |
| 40 | KHSB 40 | BW | Gajminhal | 218.85 | Very Poor Water |
| 41 | KHSB 41 | BW | Madanbhavi | 288.34 | Very Poor Water |
| 42 | KHSB 42 | HP | Somanhatti | 338.86 | Water unsuitable for drinking |
| 43 | KHSB 43 | HP | Somanhatti | 113.58 | Poor Water |
| 44 | KHSB 44 | HP | Chachadi | 123.65 | Poor Water |
| 45 | KHSB 45 | BW | Yargatti | 103.35 | Poor Water |
| | **Note: Where, KHSB-Kanavi Halla Sub Basin, BW- Bore wells, HP- Hand Pumps** | | | | |

Table 5.20(b) Calculation of WQI for individual water samples (POM)

| Sl.No | Sample | Source | Village | WQI Value | Classification |
|---|---|---|---|---|---|
| 1 | KHSB 1 | BW | Nugganatti | 49.14 | Excellent Water |
| 2 | KHSB 2 | BW | Yarjarvi | 111.51 | Poor Water |
| 3 | KHSB 3 | BW | Kottur | 103.57 | Poor Water |
| 4 | KHSB 4 | HP | Madamgeri | 66.51 | Good water |
| 5 | KHSB 5 | BW | Gudmadgeri | 123.13 | Poor Water |
| 6 | KHSB 6 | HP | Kurbagatti | 241.51 | Very Poor Water |
| 7 | KHSB 7 | BW | Kodlivad | 100.74 | Poor Water |
| 8 | KHSB 8 | HP | Hire Nandi | 230.27 | Very Poor Water |
| 9 | KHSB 9 | HP | Chick Nandi | 210.94 | Very Poor Water |
| 10 | KHSB 10 | HP | Mamadapur | 321.09 | Water unsuitable for drinking |
| 11 | KHSB 11 | HP | Upparatti | 313.32 | Water unsuitable for drinking |
| 12 | KHSB 12 | HP | Maladinni | 334.07 | Water unsuitable for drinking |
| 13 | KHSB 13 | HP | Makalageri | 211.55 | Very Poor Water |
| 14 | KHSB 14 | HP | Pudalakatti | 149.94 | Poor Water |
| 15 | KHSB 15 | BW | Siltibavi | 134.39 | Poor Water |
| 16 | KHSB 16 | BW | Jamnal | 192.66 | Poor Water |
| 17 | KHSB 17 | BW | Khanagaon | 187.74 | Poor Water |
| 18 | KHSB 18 | HP | Kaitnal | 54.5 | Good water |
| 19 | KHSB 19 | HP | Madhuval | 149.31 | Poor Water |
| 20 | KHSB 20 | BW | Ajjanakatti | 544.76 | Water unsuitable for drinking |
| 21 | KHSB 21 | HP | Yaraganvi | 154.74 | Poor Water |
| 22 | KHSB 22 | BW | Halaki | 132.42 | Poor Water |
| 23 | KHSB 23 | HP | Halaki cross | 133.53 | Poor Water |
| 24 | KHSB 24 | BW | Tadaslur | 97.87 | Good water |
| 25 | KHSB 25 | HP | Malagali | 107.97 | Poor Water |
| 26 | KHSB 26 | HP | Hire Budnur | 95.97 | Good water |
| 27 | KHSB 27 | HP | Chikk Budnur | 121.35 | Poor Water |
| 28 | KHSB 28 | HP | Vannur | 163.91 | Poor Water |
| 29 | KHSB 29 | HP | Vannur/Maclm | 235.27 | Very Poor Water |
| 30 | KHSB 30 | HP | Mechalamaradi | 78.85 | Good water |
| 31 | KHSB 31 | HP | Nesargi | 160.8 | Poor Water |

| | | | | | |
|---|---|---|---|---|---|
| 32 | KHSB 32 | HP | Sutagatti | 153.05 | Poor Water |
| 33 | KHSB 33 | BW | Desnur | 48.17 | Excellent Water |
| 34 | KHSB 34 | BW | Mohre | 94.26 | Good water |
| 35 | KHSB 35 | BW | Mallapur | 139.95 | Poor Water |
| 36 | KHSB 36 | HP | Hanabarahatti | 249.37 | Very Poor Water |
| 37 | KHSB 37 | BW | Gajaminhal | 362.43 | Water unsuitable for drinking |
| 38 | KHSB 38 | BW | Madanabavi | 313.75 | Water unsuitable for drinking |
| 39 | KHSB 39 | HP | Somanatti | 321.61 | Water unsuitable for drinking |
| 40 | KHSB 40 | HP | Chachadi | 166.28 | Poor Water |
| 41 | KHSB 41 | BW | Yaragatti | 124.32 | Poor Water |
| **Note:** Where, KHSB-Kanavi Halla Sub Basin, BW- Bore wells, HP- Hand Pumps | | | | | |

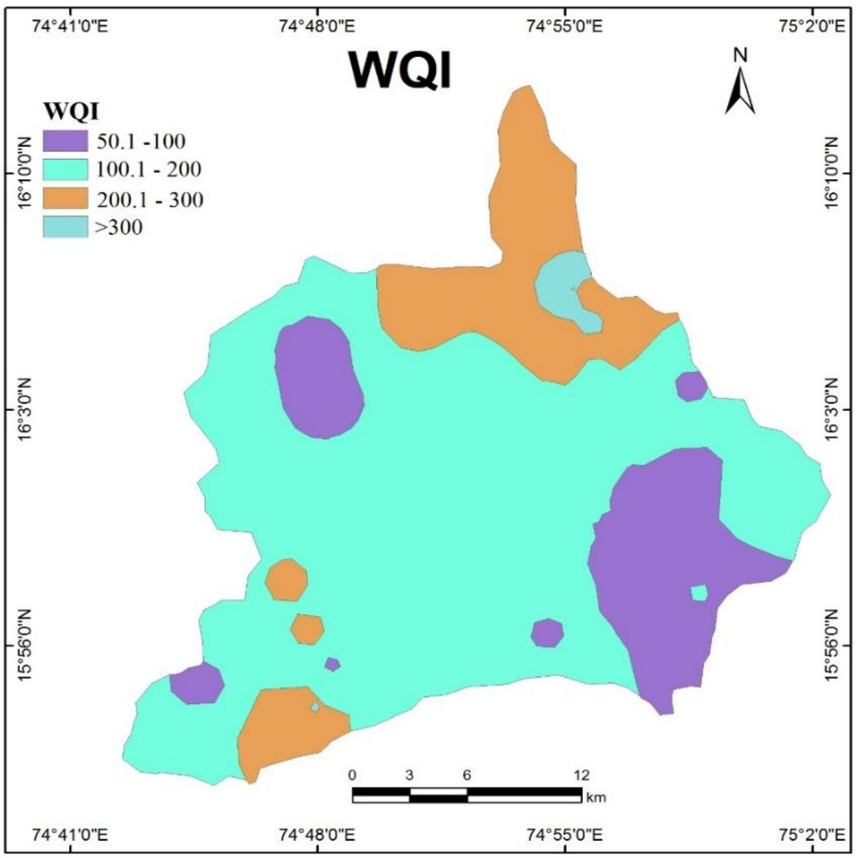



Figure 5.29(a) Water quality index map(PRM)

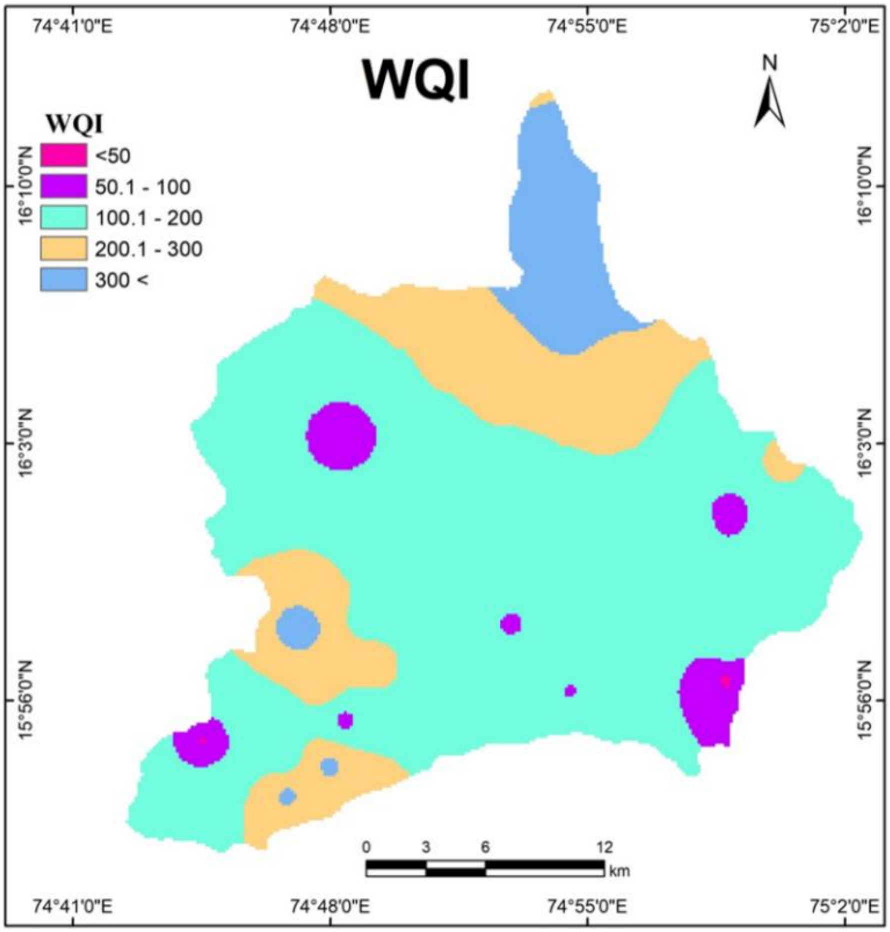



Figure 5.29(b) Water quality index map(POM)

Based on 14 parameters of groundwater quality, WQI is computed and spatial variation is represented in figure 19. This shows that 2/3$^{rd}$ of the KHSB, groundwater quality is poor to the very poor condition. Hardly 26% and 19.5 % of groundwater quality is good to excellent in condition for drinking purposes in PRM and POM respectively. Groundwater is unfit for drinking purposes in the extreme northern part of KHSB. Thus, the KHSB is affected by water quality problems.

The spatial distribution pattern maps for all fourteen parameters have been prepared (Figure 20.a, 20.b ,20.c). These maps depict that the groundwater in KHSB is dissolved by excess concentration of EC, TDS, $HCO_3$, Na and TH that are detected in the northern part of the study area. The maximum part of the KHSB is characterised by means of higher pH and $HCO_3$ value that indicates that the ground water is more alkaline nature, apart from the eastern part and extreme south western parts which have comparatively little variation. It is sympathetic that the southern and NE part of the KHSB is subjected to higher concentration of $NO_3$. South western part of the KHSB is influenced by excess concentration of Mg, $NO_3$, Cl, $SO_4$, Fe and F. Higher concentration of K is observed towards the northern part of KHSB. Based on the spatial distribution maps it can be concluded that each parameter is having higher concentration in one or the other parts of the KHSB. Maximum part of the KHSB is having higher concentration of majority parameters.

### 5.4 Summary

Hydrogeochemical study in KHSB for both drinking and agricultural suitability reveals as most of the sample are exceeding the limits as according to the recommended various standards of drinking water quality. Based on the spatial distribution maps it can be concluded that each parameter is having higher concentration in one or the other parts of the KHSB. In the PRM experimental results show, 3 samples for chloride, 2 samples for sodium percentage, 3 samples for permeability index (PI), 2 samples for MAR, 5 sample for Kelly's ratio, and 1 sample is as per TDS values are unsuitable and as per RSC, EC and SAR results, all sample are suitable and lies within the permissible limit. In the POM experimental results show, 4 samples for chloride, 2 samples for sodium percentage, 4 samples for permeability index (PI), 23 samples for MAR, 33 sample for Kelly's ratio, 66 samples for RSC and 3 sample is as per TDS values are unsuitable and as per EC and SAR results, all sample are suitable and lies within the permissible limit. In both seasons Piper diagram shows the groundwater is mainly Ca-Mg-Cl and Ca-Mg-$HCO_3$ types are the dominant water types in the KHSB. Wilcox diagram illustrates 24 samples in PRM and 23 samples in POM comes under the doubtful to unsuitable and one sample is unsuitable.

Schoeller diagram clearly shows the Na, Ca, Cl, Mg and $HCO_3$ are the chief ions in the groundwater. Gibbs plot clearly shows rock dominance is influencing the chemical composition of the water since all the samples are falling in the field of rock dominance. Rock dominance is because of the weathering of rock forming minerals when water gets interacted with the rocks and dissolution takes place during the time of infiltration as well when storehouse of water it is surrounded by the rocks. US salinity diagram groundwater samples are classified as high salinity- low sodium hazard and few samples are under medium salinity-low sodium hazard and very high salinity-low sodium hazard. The dominance of cations are in the order of Ca > Na > Mg > K > Fe and of anions is $HCO_3$ > Cl > $SO_4$ > $NO_3$ > F based on their average value of each ion in KHSB.

Descriptive statistics are drawn for the whole set of groundwater quality data to give a brief view and also to understand the variance of the data. The Pearson correlation matrix is generated and represented with the scatter matrix plot, which is useful for better understanding. For the correlation matrix, four and three factors were extracted for the PRM and POM respectively with PCA technique to describe 80.28 % and 75.01% % of the variance correspondingly and it is described from four and three components along with the scree plot for the PRM and POM respectively. From the Correlation coefficient and factor analysis using PCA for water quality data set for the KHSB revealed that, geological processes like weathering and dissolution of minerals, fertilizers and other organic matter from agricultural activities and where the source is non-agricultural, rainfall and domestic wastewaters are the main reasons behind the variation of groundwater quality. Easily observable facts and data about the practices in the KHSB are made the interpretation of each factor much easier since some of the activities like agriculture, domestic works and industries were running during the observation period. The non-mixing or partial mixing of different kinds of groundwater highlights the sluggish movement or less infiltration or the lacking of the interconnected underground fractures. This investigation also explains the use of the multivariate statistical application in the hydrogeochemical analysis. The chances of failure of this kind of analysis may be due to the inadequate data, inappropriate frequency of observation of data and manmade errors during the analysis of the quality variables in the research laboratory. Because of this, it is necessary to give more stress on observed data to be very systematic before to use in this analysis. For this sake we have cross verified the data adequacy with the help of KMO and Bartlett's test, where results showed more than the minimum value.

The Saturation indices values depicts as halite, anhydrite and gypsum that are in the undersaturated state, while those of calcite, dolomite and aragonite ranged from saturated to undersaturated state. Based on the water quality index results and spatial distribution of the KHSB shows that 66%, groundwater quality is poor to very poor condition and around 26% falls under the good condition in PRM whereas, in POM it shows that 63%, groundwater quality is poor to very poor condition and around 19.5% falls under the good condition. The extreme northern portion of the KHSB is completely unfit for drinking.

# CHAPTER-6

# GROUNDWATER RECHARGE STUDIES

## 6.1 INTRODUCTION

In arid and semi-arid regions, groundwater is a significant part of the total water resources. Our very own survival on earth depends on two basic resources water and soil, which are nature's two valuable gift to mankind. Groundwater is a crucial and economic source of fresh water throughout the world, however it is a limited natural resource (Roshni,, et al. 2022). The importance of groundwater as a resource has never been as much discussed as it is today. Groundwater resources are extremely significant in the areas of arid and semi-arid tropics particularly in the hard rock terrains. For nourishment of any lifecycle and for any developing activity, groundwater acts as a world's utmost precious and important natural resource (Hutti and Nijagunappa 2011; Ghosh et al., 2016). One of the most important and depleting resource in both rural and urban areas is water. In densely populated countries, the demand for water is high hence the groundwater demand increases. Variation in the climatic conditions are badly affecting the monsoon seasons and due to the over exploitation of groundwater to meet the requirements leading to depletion in groundwater level which will further effect on investment and operational cost. Percolation of the rain water into the subsurface has diminished significantly, because of developmental activities in urban areas which results in the reduction of availability of groundwater tremendously.

Evaluating, handling and development of this resource for sustainable usage grow into vital problem in human life, particularly in the area with low and erratic rainfall and deeper level of groundwater occurrence (Jasrotia, et. al., 2009). Effective planning of consumption of groundwater is of extreme importance (Kumar, M. G. et.al., 2008). In defining groundwater recharging potential zones (GWRPZ) in regions of hard rock, some very extensive research on hydrogeology have been done by a number of scholars and academics. Especially the countries like India, areas which are semi-arid and hard rock regions are facing regular water inadequacy events generally in summer months and also in drought years.

In India the rainfall is extremely variable due to the different rainy season pattern and diverse topographical conditions like plane land, mountain, valley etc. Spatially rainfall is 100 mm which is very low in Rajasthan and 11,000 mm in Mausingram, Meghalaya (Sharma and Paul, 1998). Even in national agricultural and water policy of Government of India, the prerequisite of water recharge and water conservation has been stressed. The various structures for groundwater recharge, like check dams, nalla bunds, percolation tanks, harvesting bunds, farm bunds etc. are built at suitable site that check water flow, flood and afford agriculture to downstream areas and also influences groundwater recharge (Singh et al., 2009).

Recharge of groundwater is extremely low in hard rock terrains due to the low permeability and lack of weathered, fractured and jointed zones in the subsurface. A lesser amount of annual rainfall is also a reason for depletion of groundwater. Chances of failure of bore wells in such areas is high due to lack of groundwater. While the Indian subcontinent receives a substantial annual rainfall, its distribution across the country is not only uneven but also unpredictable. Groundwater development in the region operates as an individual endeavor without any legislation regulating the management of this crucial resource, which holds immense importance for agriculture (Raju, 1998). Both the central and state governments have initiated several artificial recharge projects, primarily in the form of pilot projects. These endeavors have shown promising prospects and potential for artificial recharge.

Groundwater recharge occurs naturally and artificially. But to meet the human requirements there is a need of artificial groundwater recharge, to enhance the quantity as well as quality. Infiltration is the process through which natural groundwater recharge takes place by percolating from earth’s surface to subsurface and which reaches either to the confined aquifer or unconfined aquifer. Aquifers will form based on these two kind of recharge processes, whereas decrease in the infiltration or groundwater recharge will make the subsurface dry and aquifers become empty. Groundwater recharge structure is significant mechanism of watershed improvement. Since the amount of normal precipitation is totally insufficient, enhancement of aquifers by artificial groundwater recharge methods especially in the arid and semi-arid areas of India is crucial, as the intensity of normal rainfall is totally insufficient to produce any moisture surplus under normal infiltration conditions (Mukherje, D. 2016).

Selection of any specific method for artificial groundwater recharge depends on the various criteria like topography of the area, lithological variations, geomorphological observations, rainfall trend and many more. Remote sensing and geographic information system (RS and GIS) are the modern practices becoming significant in the present days. Geoinformatic tools perform a vital role in the development in the field of hydrology (Krishna, A. P. 1996, 2005; Durga Rao, et al., 2001; Anbazhagan, S., & Ramasamy, S. M. 2001; Kumari, N., & Krishna, A. P. 2013). They play a crucial role for successful analysis of any hydrological investigations to collect information, especially in spatial and temporal domain, which is the greatest advantage of using both RS and GIS.

This chapter mainly deliberates on the methodology to locate suitable site selection for artificial groundwater recharge. This chapter also presents identification of most favourable locations for groundwater recharge (GWR) and suggests suitable structures using decision support system (DSS) which is based on GIS that uses remotely sensed data and limited field survey. These methods have enough potential of enhancing the water resources by integral approach by using the recent developments. Hence location of groundwater recharge sites and construction of suitable structures are very much needed since the majority of area in the hard rock areas of India is semi arid and rain fed because of erratic precipitation. Available excess runoff due to rainfall need to be collected in respective structures for better use of it for agricultural, domestic and industrial requirements (Kadam et al., 2012). Remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units/landforms/lineaments due to the synoptic and multi spectral coverage of terrain. Satellite images are increasingly used in groundwater exploration because of their utility in identifying and outlining various groundwater features that may serve as direct or indirect indicators of the presence of groundwater as well to locate the suitable sites for groundwater recharge.

For mapping suitable sites for groundwater recharge zones individual thematic maps are prepared from the satellite data, toposheet, field survey and available secondary data. Conclusions drawn based on the existing literatures as there is a need of addition of some more thematic layers to enhance the accuracy level hence here the thematic layers like water quality index (Post Monsoon), various D-Z parameters were considered, viz., longitudinal unit conductance (S), transverse unit resistance (T) and electrical anisotropy (λ).

Hence after reviewing various literatures in order to delineate the potential sites for groundwater recharge/groundwater potential zones the following thematic layers are most commonly used.

Lithology/geology + Slope + Geomorphology + lineament + landuse/landcover + Soil type + slope + drainage + Rainfall + Groundwater contour

Literatures reveals that the output map of site suitability map of groundwater recharge can be enhanced by considering water quality index and various D-Z parameters could be advantageous for numerous purposes like to develop the schemes for sustainability of groundwater along with the delineation of groundwater potential zones. Groundwater reserves can be developed in less time and at less cost, and more importantly, without causing too much hazard to environment by keeping the exploitation within permissible limits. For such development, remote sensing and GIS, geophysical techniques, groundwater quality hydrochemistry, electrical resistivity in particular, play leading role in groundwater recharge studies.

## 6.2 MATERIALS AND METHODOLOGY

### 6.2.1 Creation of Thematic maps

The various maps collected from different organizations were digitized and remote sensing data is processed using ArcGIS10.3. A total of 11 necessary thematic layers geology, soil type, geomorphology, slope, drainage density, lineament density, water quality index, lu/lc, electrical anisotrophy, longitudinal unit conductance and transverse unit resistance have been considered based on their influence for preparation of potential groundwater recharge zones.

The geology map of 1:50000 scale and geomorphology map has been prepared from the published maps by Karnataka State Remote Sensing Applications Centre (KSRSAC). The slope map and drainage patterns were extracted from the 1 arc sec SRTM DEM data. Type of soil in the area has been identified by the published maps of National Bureau of Soil Survey & Land Use Planning (NBSS & LUP). Land use/ land cover (LU/LC) map has been prepared using the RESOURCESAT-I LISS-IV (Resolution 5.8m) data. The LISS-IV data is also used to extract lineaments of the study area. Later drainage data and lineaments data also used to prepare the drainage density and lineament density maps respectively. All the prepared thematic layers were in Universal Transverse Mercator(UTM) coordinate system and WGS84 spatial reference.

In the current study, the Dar-Zarrouk (D-Z) parameters, viz. transverse unit resistance (T), longitudinal unit conductance (S), electrical anisotropy($\lambda$) and have been considered to evaluate the VES data and to create thematic layers. These parameters calculation has been discussed in chapter 4.

Water quality index (WQI) has been also considered and the procedure for calculation and WQI map preparation has been discussed in the chapter 5.

The prepared thematic maps have been later integrated with one another through GIS environment using weighted overlay method to derive the suitable sites for groundwater recharge structures. All the thematic layers which are considered here are interrelated to each other and helpful to produce the maps which will show the suitable sites for ground water recharge. List of thematic layers, source for thematic layers and methodology for preparation of site suitability map for groundwater recharge has been shown in the figure.6.1.

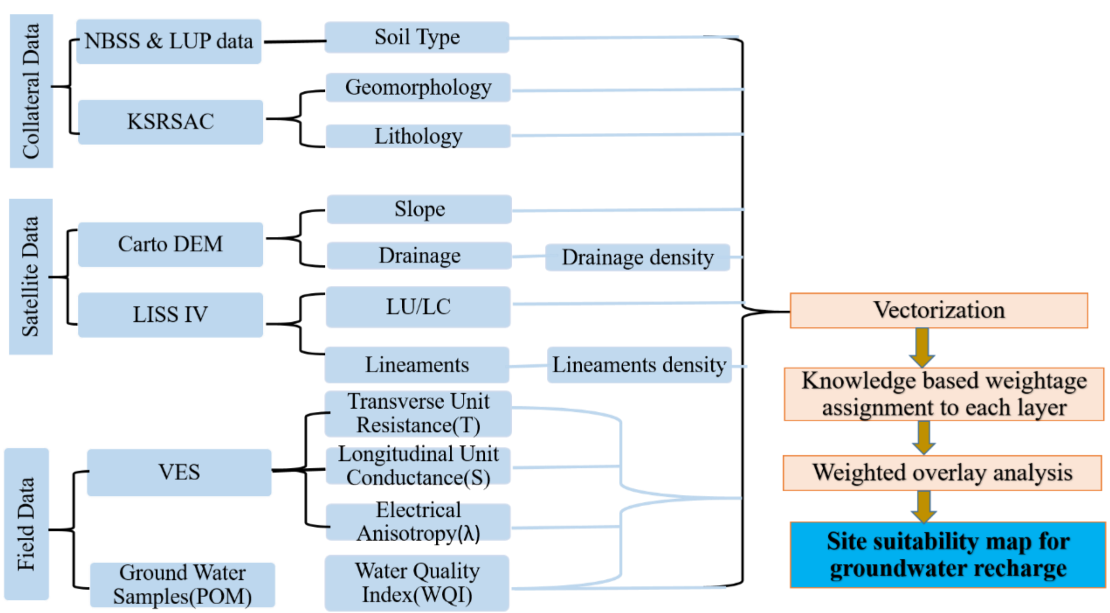



Figure.6.1 Flow chart for site suitability map for groundwater recharge

By knowledge based weightage assignment to each layer suitable sites for groundwater recharge zones has been classified by considering all the influencing factors and their importance in groundwater occurrence as (1) High, (2) Moderate, (3) Low, (4) Very low.

## 6.3 Factors influencing Ground Water Recharge

Identification and location of GWRPZ depends on direct analysis of some observed topographical features like geological and geomorphic and their hydrologic characters. It is necessary to know the depth of the bedrock and the permeability and porosity of the area to increase the accuracy level considering the subsurface layer using vertical electrical sounding approach.

### 6.3.1 Geology

Geology of any area plays a pivotal role in defining its subsurface hydrogeological conditions. Lithounits found in the study area includes- arenites along with shale and limestone, argillites with dolomite with quartzite, alluvium, basalt, metagreywacke, granite gneiss.

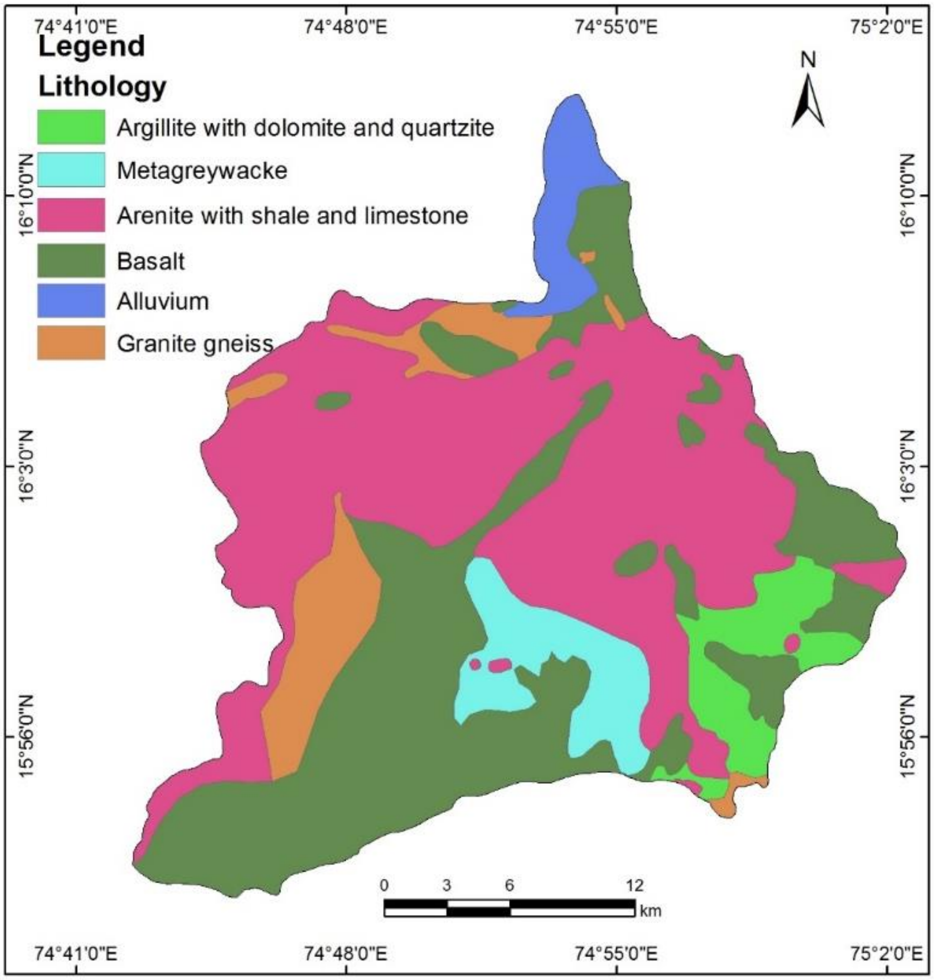



**Figure 6.2 Geology of the Study Area (after GSI)**

Based on the hydrogeological properties of the above rocks the general ground water potential/recharge conditions can be categorized into moderate to good. In rocks such as alluvium, arenites, argillites, metagreywackes. Ground water can be found to be present at shallow depth due to its property of porosity and permeability while in basalts and granite gneiss the depth vary from shallow to deeper levels depending upon the secondary porous media (fractures/joints) as these rock types lack primary porosity (Asode et al. 2016; Talwar et al., 2015). Geology of the study area has been shown in figure 6.2.

### 6.3.2 Soil type

In the present study dominantly only two types of soils are found viz., black and red soil. These soils are clayey in nature. Black soils are typically of Deccan Traps which are porous and permeable implying good infiltration on the contrary red soils are of gneissic which are loamy in nature. Alluvial black soils are also observed which generally is very thin cover but has very good infiltration characteristics and are composed of coarse sand, sandy-loam and loams. Further, the depth and texture of these rocks vary from place to place depending upon the parent rock types (CGWB Report, 2012). Therefore, area with black soils are good for ground water recharge and yield good water as compared to area covered with red soils further, subjected to subsurface formations. Soil types of the study area has been shown in figure 6.3.

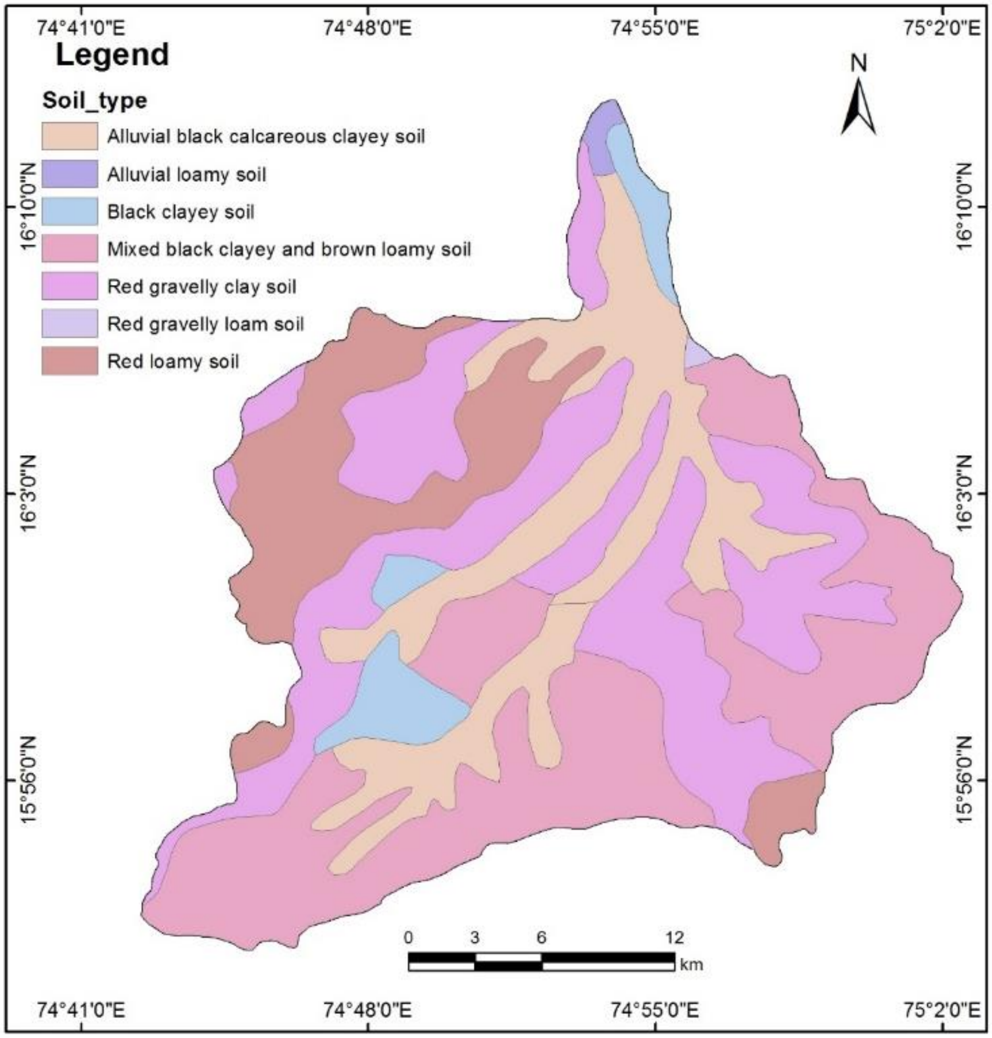



Figure 6.3 Soil Types of the Study Area (After NBSS & LUP)

### 6.3.3 Drainage Network

Geomorphology and morphometric parameters serve as valuable tools in the analysis of drainage networks. They offer insights into lithology, hydrological features, drainage characteristics, and the exogenic or endogenic processes operating within the basin. Based on the shape and pattern of drainage network of study area it is found to be elongated and dendritic to sub-dendritic in nature. Drainage factor is primarily dependent on the underlying lithology, so it is a key indicator for identification of water infiltration as indicated by Shaban et al. in 2006. Ghosh et al., 2016 clearly mentioned that, higher the density of drainage, lesser the recharge rate and vice versa. With regard to extraction of more appropriate drainage pattern, manual extraction is more preferable rather than one which is created from the satellite imageries (Tribe, 1991; Ichoku et al., 1996; Martinez-Casasnovas and Stuiver, 1998). Drainage Pattern of the study area has been shown in figure 6.4. Drainage Map was prepared from the SRTM DEM.

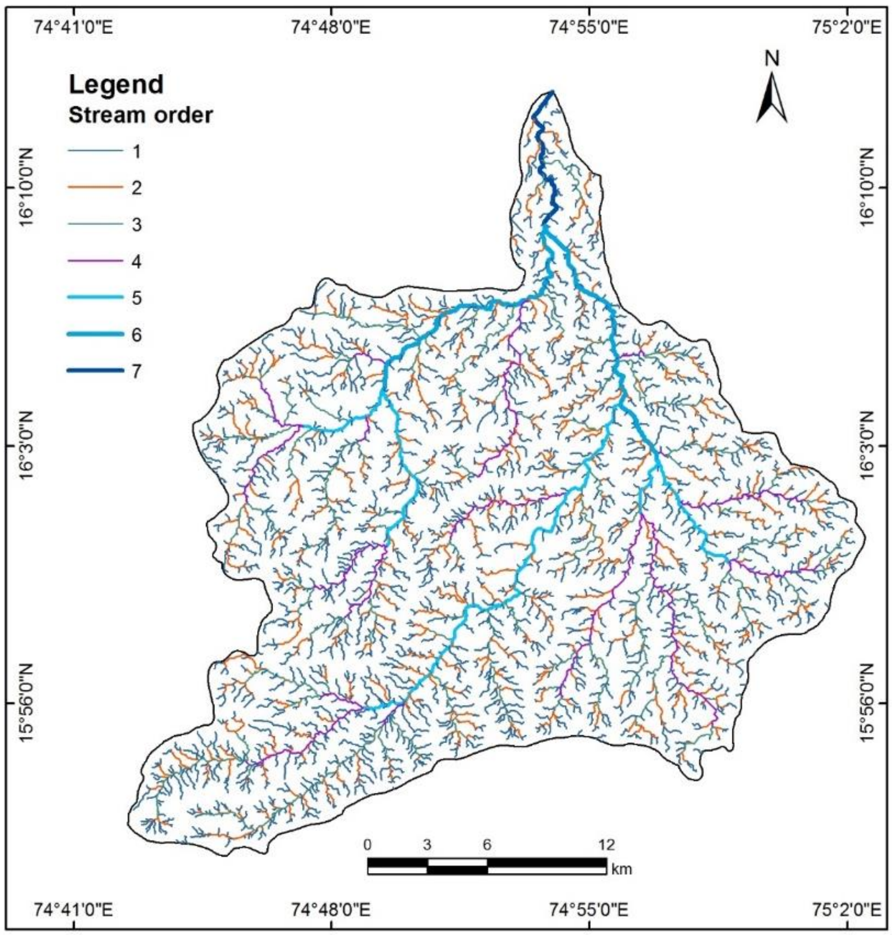



Figure 6.4 Drainage Map of the Study Area

### 6.3.4 Drainage Density

Characteristics of groundwater runoff and infiltration of study area can be understood with the help of drainage pattern. Extracted DEM is used for density map (Figure 6.5) preparation and analysis. The correlation between drainage density and groundwater recharge is noteworthy. Areas exhibiting high drainage density typically indicate elevated levels of groundwater recharge. This density map assigns values based on the intensity of the drainage pattern observed in different zones. In the present study the regions were classified as 0.13-0.20, 0.21-0.27, 0.28-0.33, 0.34-0.39 and 0.40-0.45 km/km$^2$.

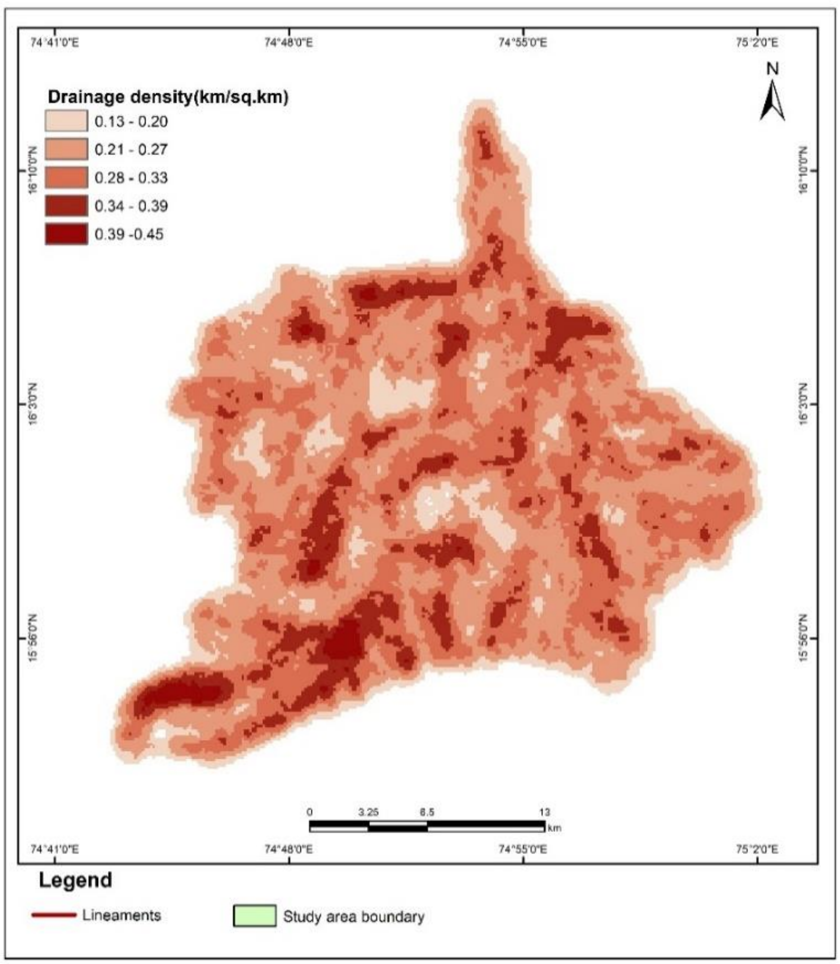



Figure 6.5 Drainage Density Map of the Study Area

### 6.3.5 Geomorphology

Geomorphology maps were compiled using data sourced from KSRSAC, forming a crucial component discussed extensively in Chapter 3, "Geology and Geomorphology." Geomorphology profoundly influences the suitability of sites for groundwater recharge studies, hence meriting a substantial weightage of 15 for this thematic layer. Notably, features like Pediplain weathered/buried and Water Bodies hold a high ranking of 5 due to their ability to impede water flow, allowing for enhanced water storage and infiltration, thereby elevating recharge potential. Conversely, structural hills received the lowest ranking of 1 due to their terrain characteristics that accelerate water flow, resulting in reduced recharge potential areas.

Geomorphological studies encompass the delineation and mapping of diverse landforms and drainage features that exert direct influence on the presence and movement of groundwater. These mapping endeavors play a crucial role in identifying zones conducive to groundwater recharge and their suitability for groundwater development (Singhal and Gupta, 1999). Geomorphology stands as a pivotal factor dictating the groundwater dynamics in any geographical area (Singh, 1999; Ravi Shankar and Mohan, 2005; Mondal et al., 2007; Gurugnanam et al., 2008; Raghu and Reddy, 2011). Geomorphic units identified in the study area include- structural hills, pediment, pediplain, inselberg, plateau, mesa and butte (Figure 6.6). Structural (hills) features facilitate infiltration of water and contain springs/seepages at lower part, although these regions normally have poor source of groundwater. A pediment is a geomorphic feature formed through erosion, typically characterized by a thin layer of sediment deposition that primarily surrounds the edges of elevated rock outcrops. In this unit, groundwater prospects are normally poor due to massive rocky surface, whereas in granitic terrains with numerous fractures or joints permit infiltration and storage of groundwater. Hence, depending on the thickness of weathered material and the presence or absence of secondary structures, groundwater potential is moderate to poor. Inselbergs are solitary residual hillocks that remain as remnants of weathering and denudation, predominantly observed within granitic terrains.

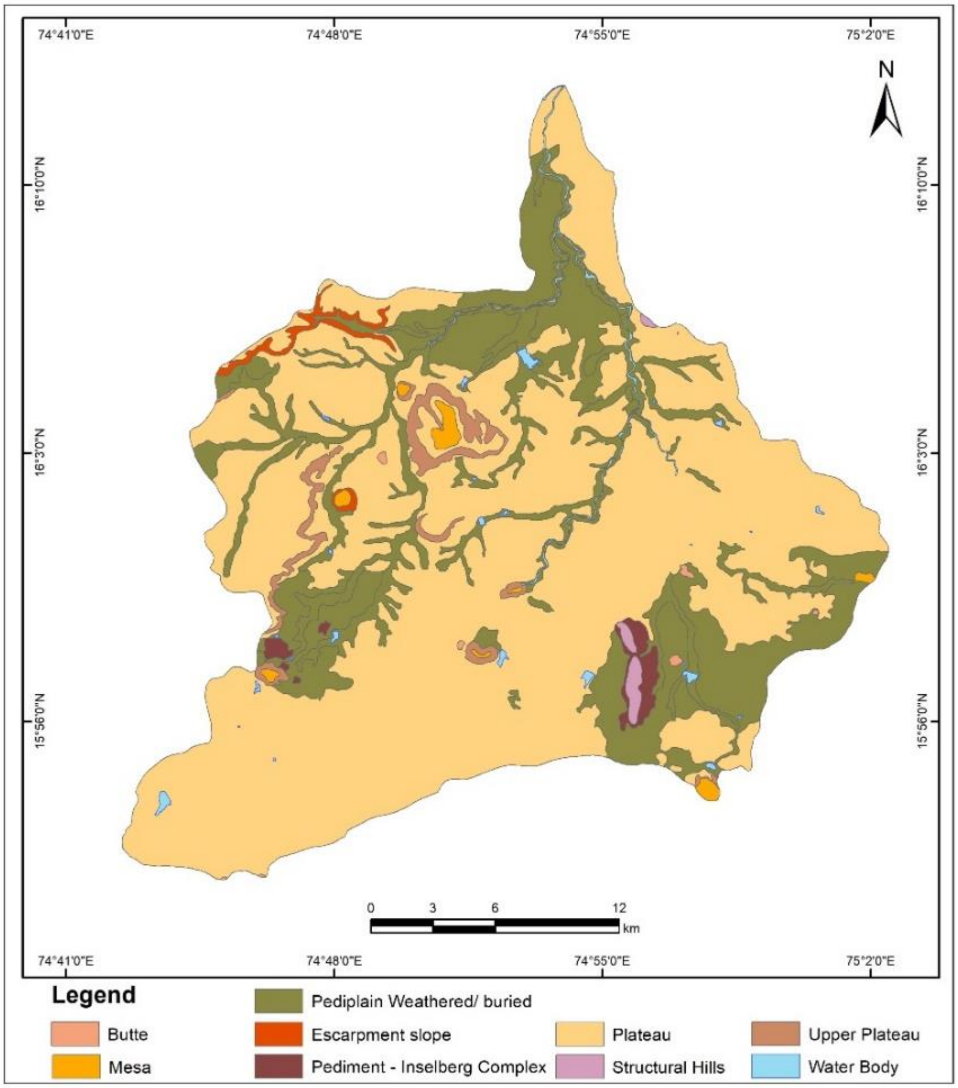



Figure 6.6 Geomorphology of the study area

This geomorphic unit acts as runoff zone, where groundwater potential is found to be almost nil. Pediplain is a result of weathering under arid and semi-arid conditions, representing the end stage of cyclic erosion (King 1950, Sparks 1960). Pediplains with more or less over burden of accumulated materials on the shallow to moderately weathered rocks have been identified in various lithological units by interpretation of soil maps and the field survey. Shallow weathered pediplain is developed by continuous process of pedimentation at low gradient and covered with shallow weathered material and sparse vegetation. Groundwater prospect is found to be poor (virtually dry environment) to moderate (gentle slopes adjacent to the stream courses/tanks) in this type of pediplain. Moderately weathered pediplain is found as nearly flat terrain with gentle slope and occurs normally along all the major drainage courses/broken streams, which control the valley course. Hence, groundwater prospects in this unit are considered as moderate to good, depending upon the thickness of weathered zone (K. Avinash et al., 2011). Plateaus in the study area are typical units derived from Deccan traps. These range in highly dissected to moderately dissected to undissected plateaus. Highly dissected are regions were no considerable source of ground water are found as these are restricted to hills and foot-hills where gradient is quite low where as in moderately dissected to undissected plateaus moderate to good aquifer zones can be found (Varade et al., 2017).

### 6.3.6 Lineament

A lineament can be defined as a large-scale linear structural feature resulting from natural processes, encompassing deep-seated faults, master fractures, joint sets, bedding planes, foliation, drainage lines, and boundaries between litho-units and stratigraphic formations (O'leary et al., 1976; Anudu et al., 2011). These features manifest on the Earth's surface as straight streams and valleys, aligned surface depressions, changes in soil tonal patterns, alignments in vegetation, alterations in vegetation type and height, or abrupt shifts in topography.

Recognizing the significance of lineament structures in groundwater studies, the lineaments within the study area have been interpreted and extracted from satellite imagery (Figure 6.7). This interpretation aids in precisely identifying potential zones for groundwater exploration and facilitates the selection of sites for constructing water conservation structures. Further, depending upon the frequency and density of lineaments these are the places are underlined by highly fractured/weathered and increased porosity and permeability (Varade et al., 2017). These places act as good source for ground water recharge and potentials (borewells).

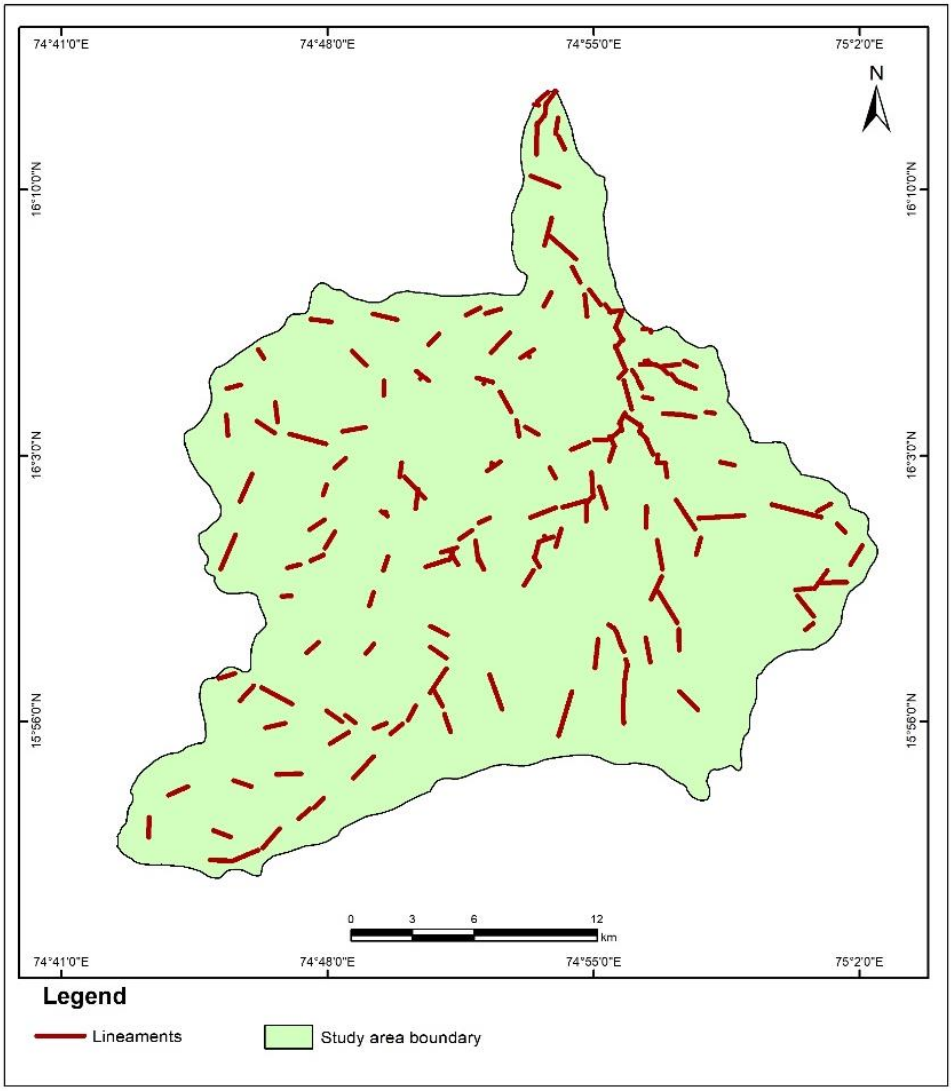



Figure 6.7 Lineament map of the study area

### 6.3.7 Lineament Density

Lineaments are generally referred to know the groundwater movement and storage (Selvaum et al, 2016; Magesh et al, 2016). Lineament map is used to extract the lineament density map in the present study. The density of lineaments and intersection of lineament do have an influence on groundwater availability. Linement density map is classified as 0-0.039, 0.04-0.25, 0.26-0.43, 0.44-0.69 and 0.7-1.3 km/km$^2$.

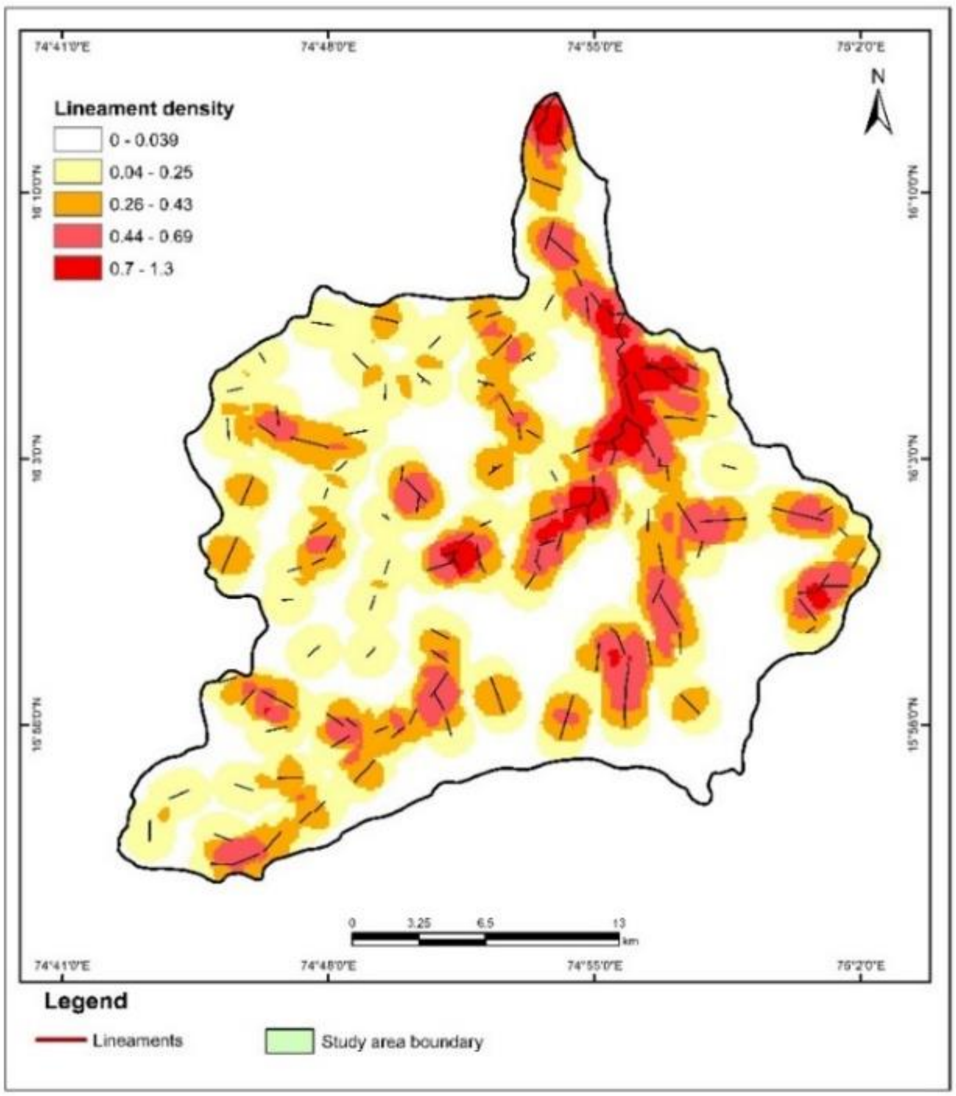



Figure 6.8 Lineament Density map of the study area

The figure 6.8 shows a low density in most of the are compared to other parts of the KHSB. The areas with high lineament densities were found to be related with good groundwater recharge and potential zones in the basin.

### 6.3.8 Slope

The gradient of the terrain significantly influences the generation of stream networks, as well as runoff and flooding. Water tends to follow the path of maximum slope, and a steeper slope elevates the velocity of stream flow, consequently reducing the time of concentration and leading to erosion. A high slope diminishes the length of overland flow, causing water to swiftly trace the channel path and contributing to the rapid rise of the hydrograph. Surface vegetation cover and channel gradient are crucial factors in this context. Dense vegetation cover tends to mitigate the flow and sediment compared to areas with sparse vegetation cover, assuming all other external forces act uniformly throughout the area (Vuppala et al., 2004; D. R. Samal et al., 2015). This implies that the flatter the topography is the better are the chances for groundwater accumulation. In the present study general slope varies from 0-36$^{o}$ but most part of the area are in the range 0-10 degrees (Figure 6.9).

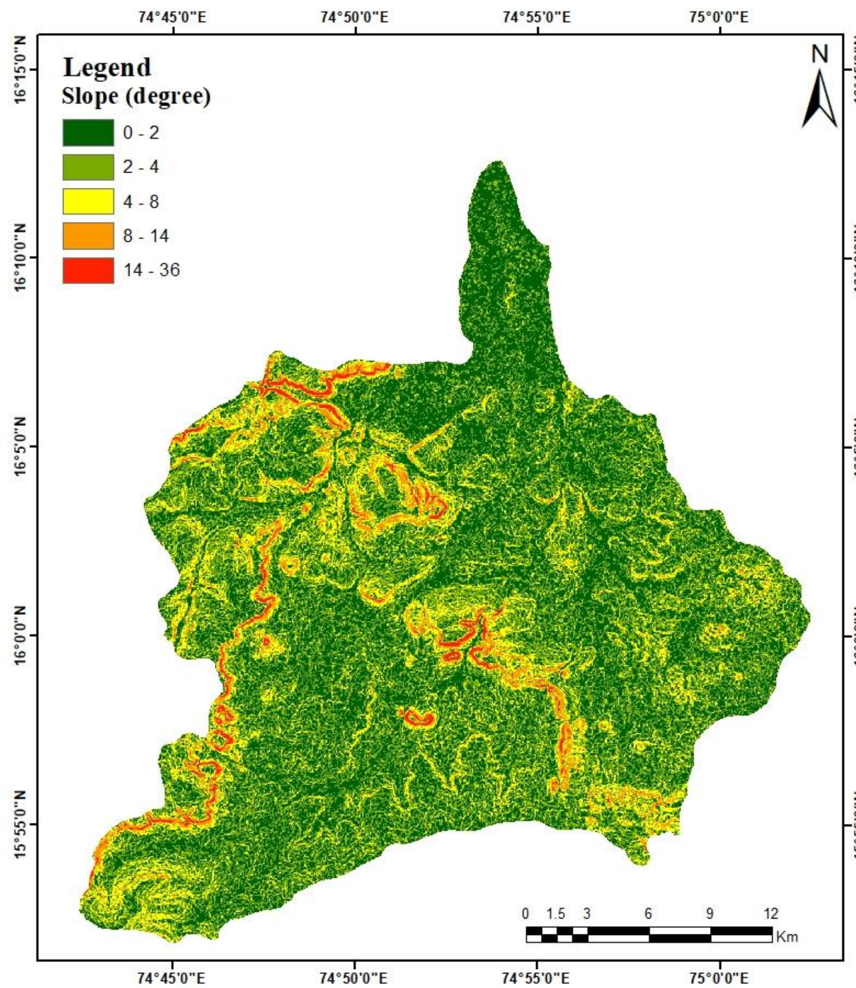



Figure 6.9 Slope map of the study area

The slope layer is prepared using the SRTM DEM. Slope is having an inverse relation with groundwater infiltration. Higher the slope more runoff and thus decline in the infiltration and disturbs groundwater recharge. Therefore, ranking of 1 is given to highest slope and 5 for lowest slope.

### 6.3.9 Land Use/ Land cover Map

LU/LC map was classified into seven classes, as agriculture (65.2 %), Scrub land (8.48%), forest (20.77%), barren rocky (0.02%), builtup (2.66%), water bodies (1.75%) and mining/industries (1.21%) as shown in Figure 6.10. An accuracy assessment of the LULC map was determined on the basis of ground truth information of 50 sampling locations. Almost, 85 % of the total area is covered by agricultural and forest land. LULC affects the surface runoff, evapo-transpiration and groundwater recharge. Water body, agriculture land and the forest area are excellent sources of groundwater recharge, while the builtup, scrub land, mining/ industries and barren rocky areas are considered to be less significant. Therefore, highest weightage is given to water body, and lowest for the barren rocky and urban area for groundwater recharge as shown in Table 6.1.

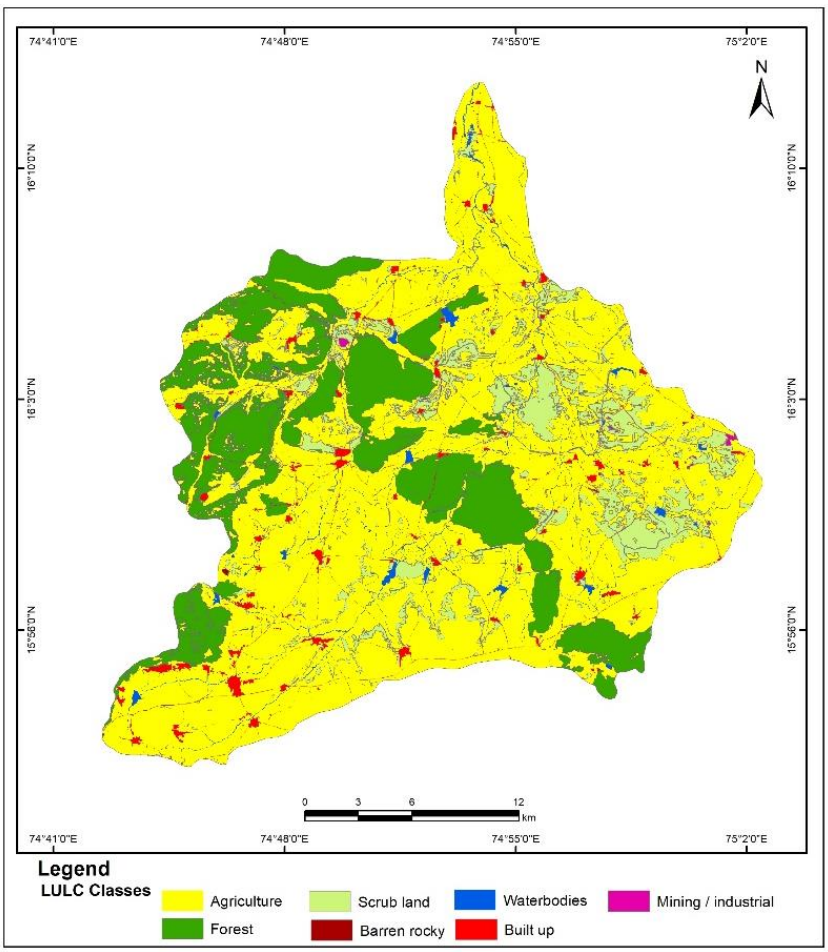



Figure 6.10 Land Use/Land Cover map of the study area generated using IRS LISS IV satellite data of the year 2009

### 6.3.10 Water Quality Index

Recharge also plays an important role improving the quality of the groundwater by increasing the quantity. Hence an attempt is made to consider this layer as an addition for groundwater recharge site suitability. WQI has been discussed in chapter 5. Most of the KHSB is covered by "poor water" and it occupies almost 467.64 $km^2$. The area is occupied by excellent water, good water, very poor water, and water unsuitable for drinking. Here the rank 5 has been assigned to unfit water for drinking and 1 has been assigned to excellent category water. Majority of the samples are falling in the "poor water" class.

### 6.3.11 Dar-Zarrouk (D-Z) parameters

A total of 40 VES were carried out using Schlumberger configuration in the KHSB. In this recharge studies the various D-Z parameters were considered, viz., longitudinal unit conductance (S), transverse unit resistance (T) and electrical anisotropy ($\lambda$) to locate the potential zones for groundwater recharge and also to delineate the fresh groundwater zones and to examine the saline water intrusion. The details of D-Z parameters have been discussed in chapter 4.

## 6.4 RESULTS AND DISCUSSION

### 6.4.1 Suitability map for groundwater recharge and discussion

All the prepared thematic maps viz. lithology/geology, slope, geomorphology, Lu/Lc, lineaments, drainage, soil type, have to be converted into raster format. Subsequently respective theme weight is to be assigned based on the field knowledge and various classes and ranks are given. So here the first step will be the weighted overlay analysis (Oikonomidis et al. 2015) which has been carried out in ArcGIS of various versions like 9.3.1, 9.3.2, 10.3 etc. In the present day.

Lithology/geology + Slope + Geomorphology + lineament density+ landuse/landcover + Soil type + drainage density + Water Quality Index+ Longitudinal unit conductance (S) + Transverse unit resistance (T) + Electrical anisotropy ($\lambda$) are considered.

The groundwater recharge potential zones can be demarcated by integrating all the thematic layers in ArcGIS. Each feature of the thematic layer was ranked and weights were assigned to every thematic layer on the basis of the previous research information and the experts opinions of the respective area of research. The knowledge based assigned ranks and weightage to each parameter is given in table 6.1.

### 6.4.2 Decision support system

After creating various thematic layers, these layers have undergone processing for various consideration. For locating potential sites for groundwater recharge (GWR) technologies, Decision support system (DSS) is the common most method which has been done using ArcGIS software. The concept of workflow is shown with flowchart in figure 6.1. The DSS has mainly three key processes which include data input and preprocessing, main processing and lastly outputs of potential sites for different types of groundwater recharge structures (Mbilinyi et al., 2007).

To achieve high accuracy, many authors have conducted ground truth survey to identify the existing structures and later compared it with the potential rainwater harvesting map by overlaying on it. This kind of investigation shows 75-100% accuracy which directs us for field application (Kadam et al., 2012).

Once we created all these thematic layers, these have been treated with different weightage based on its importance in the field. The weightage has been assigned differently for each layer like 1 to 5 with ranking or weightage in such a way that 1 is less important and 5 is highly favorable and later all these weightages will be added and based on that the area with high weightage will be treated as suitable sites for groundwater recharge.

With some surface factors, it is essential to add few sub surface or indirect factors like subsurface lithology, subsurface layers, fracture zones, water quality status to make work more accurate. The area which has got more score after all weightage assessment has been treated as more preferable. Finally, after all this analysis and overlay, we have obtained output map showing suitable site for groundwater recharge with the classifications like from poor to excellent. For artificial groundwater recharge for Indian scenario the list of thematic layers and the source for it has been given in the table 1. Based on the observation in the literatures the list which contains most preferable layers and the source which was commonly used by the maximum number of authors in the previous studies are considered.

The significant input of this work is to recommend the consideration of a new layers which are Water Quality Index of post monsson season, Longitudinal unit conductance (S), Transverse unit resistance (T) and Electrical anisotropy ($\lambda$), which are obtained by conducting Vertical Electrical Sounding (VES) with Schlumberger configuration method. Apart from that, it is also useful to know the subsurface details like fractured zone, jointed zone, faulted zone, soil depth and many more aspects. So to make recharge effectively and to increase the groundwater level effectivelly, one must carry out the VES of that particular area.

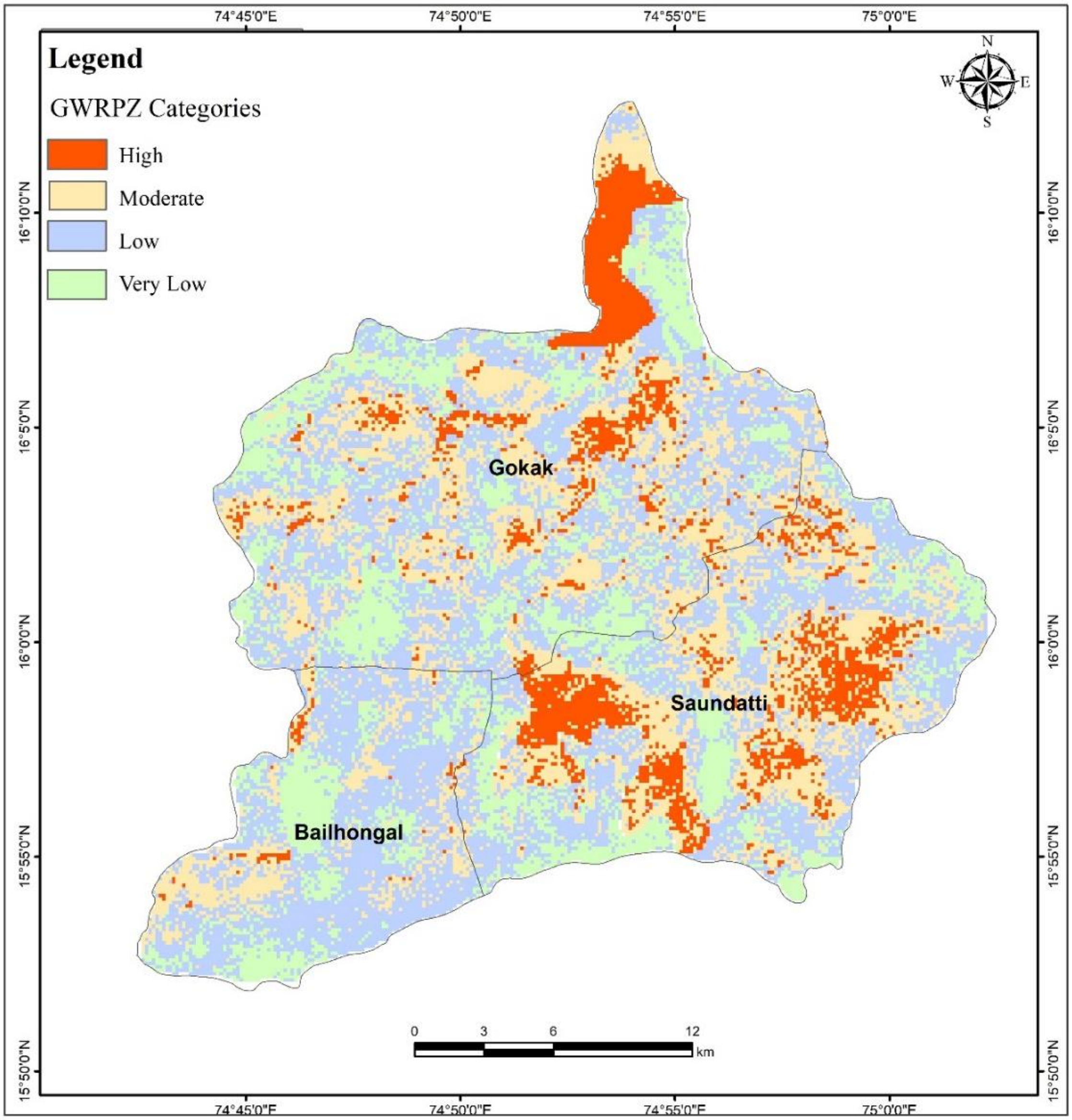



Figure 6.11 Map Showing Site suitability for groundwater recharge

## 6.5 SUMMARY

Total of 11 thematic layers are utilised for integration of Site suitability for groundwater recharge (GWRZ) mapping. They have classified as Very Low to High where the category with "Very low to low" covers maximum area. This study highlights the GIS, RS and DSS methods for site suitability study for groundwater recharge. In this study surface features like geology, geomorphology, soil type, lineament density, slope, drainage density and LU/LC are considered and subsurface features derived from water quality analysis and VES survey data are used to extract WQI, Electrical anisotropy($\lambda$), Longitudinal unit conductance (S) and Transverse unit resistance (T). Parts of Savadatti and Gokaka taluk terrains are quite good for recharge as compared to Bailhongal taluk area. Since the area is covered by hard rock terrain, recharge of groundwater in the present area is very low to low. The results show 18.7% very low, 41.2% low, 29.6% moderate, and 10.5% high, area suitable for groundwater recharge. Though several artificial recharge structures are existing in the present study area, some more check dams, farm ponds, percolation tanks and recharging bore wells are recommended in this study area. Further development of water resources in the areas like KHSB is essential since the quality is not up to the mark. These kinds of scientific approaches will enhance the accuracy level for better way of water management. Study suggests suitable sites for groundwater recharge in Kanavi Halla sub basin. This work will help in government agencies to improve the groundwater resource both in quality and quantity. The same work can be replicated in other semi-arid areas. In semi-arid, hard rock regions. Development of ground water resources for domestic as well for irrigational use is of great importance. Irrespective of morphological features like, geology, soil type, country this work can be practiced by considering little alterations, and modifications. In order to develop model efficiently one has to consider factors like agricultural condition, environmental concern, wildlife safety and socio economic factors. Hence, this case study recommends for integrated approach of VES survey, water quality study, RS and GIS along with field work for water resource management in a better way in terms of quality and quantity.

Table 6.1 Ranking, weightage and area statistics of 11 thematic layers

| Sl. No | Thematic Layer | Detailed Classes | Area $km^2$ | Assigned Ranks | Assigned Weights | Sl. No | Thematic Layer | Detailed Classes | Area (Sq.km) | Assigned Ranks | Assigned Weights |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Geology** | Argillites with dolomite and quartzite | 37.37 | 3 | | 30 | **Lineament density(km/sq.km)** | 0-0.039 | 203.92 | 5 | |
| 2 | **Geology** | Arenite with shale and limestone | 307 | 3 | | 31 | **Lineament density(km/sq.km)** | 0.04-0.25 | 261.68 | 4 | |
| 3 | **Geology** | Alluvium | 22.2 | 5 | 15 | 32 | **Lineament density(km/sq.km)** | 0.26-0.43 | 125.95 | 3 | 10 |
| 4 | **Geology** | Basalt | 229.52 | 2 | | 33 | **Lineament density(km/sq.km)** | 0.44-0.69 | 80.65 | 2 | |
| 5 | **Geology** | Metagreywacke | 40.92 | 4 | | 34 | **Lineament density(km/sq.km)** | 0.7-1.3 | 14.67 | 1 | |
| 6 | **Geology** | Granite gneiss. | 49.64 | 1 | | 35 | **Drainage Density(Km/Sq.km)** | 0.13-0.2 | 110.75 | 5 | |
| 7 | **Geomorphology** | Agriculture | 447.31 | 4 | | 36 | **Drainage Density(Km/Sq.km)** | 0.21-0.27 | 311.71 | 4 | |
| 8 | **Geomorphology** | Forest | 142.45 | 5 | | 37 | **Drainage Density(Km/Sq.km)** | 0.28-0.33 | 207.06 | 3 | 10 |
| 9 | **Geomorphology** | Scrubland | 58.16 | 3 | | 38 | **Drainage Density(Km/Sq.km)** | 0.34-0.39 | 50.22 | 2 | |
| 10 | **Geomorphology** | Barren rocky | 0.14 | 1 | | 39 | **Drainage Density(Km/Sq.km)** | 0.40-0.45 | 6.49 | 1 | |
| 11 | **Geomorphology** | Water bodies | 11.98 | 5 | 10 | 40 | **Electrical anisotropy(λ)** | <1.5 | 166.15 | 2 | |
| 12 | **Geomorphology** | Built up | 18.28 | 2 | | 41 | **Electrical anisotropy(λ)** | >1.5 | 520.13 | 1 | 10 |
| 13 | **Geomorphology** | Mining/Industrial | 8.3 | 3 | | 42 | **Longitudinal unit conductance (S)** | <0.1 | 68.6 | 1 | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | **Lu/Lc** | Structural hills | 2.68 | 1 | | 43 | **Longitudinal unit conductance (S)** | 0.1-0.19 | 102.9 | 1 | |
| 15 | **Lu/Lc** | Plateau | 479.89 | 4 | | 44 | **Longitudinal unit conductance (S)** | 0.2-0.69 | 68.6 | 2 | 5 |
| 16 | **Lu/Lc** | Mesa | 4.52 | 3 | 15 | 45 | **Longitudinal unit conductance (S)** | 0.7-4.9 | 360.15 | 3 | |
| 17 | **Lu/Lc** | Butte. | 0.9 | 2 | | 46 | **Longitudinal unit conductance (S)** | 5-10 | 51.45 | 4 | |
| 18 | **Lu/Lc** | Upper Plateau | 13.95 | 4 | | 47 | **Longitudinal unit conductance (S)** | >10 | 34.3 | 5 | |
| 19 | **Lu/Lc** | Pediment – inselberg complex | 6.1 | 4 | | 48 | **Transverse unit resistance (T)** | <700 Ω-m2 | 205.77 | 2 | |
| 20 | **Lu/Lc** | Pediplain weathered /buried | 168.95 | 5 | | 49 | **Transverse unit resistance (T)** | >700 Ω-m2 | 480.19 | 1 | 5 |
| 21 | **Lu/Lc** | Water Body | 5.4 | 5 | | 50 | **Slope** | 0-2 | 257.05 | 5 | |
| 22 | **Lu/Lc** | Escarpment slope | 4.88 | 2 | | 51 | **Slope** | 2-4 | 251.91 | 4 | |
| 23 | **Soil Type** | Alluvial black calcareous clayey soil | 131.51 | 2 | | 52 | **Slope** | 4-8 | 138.74 | 3 | 10 |
| 24 | **Soil Type** | Alluvial loamy soil, | 3.37 | 4 | | 53 | **Slope** | 8-14 | 29.58 | 2 | |
| 25 | **Soil Type** | Black clayey soil, | 30.72 | 1 | | 54 | **Slope** | 14-36 | 9.82 | 1 | |
| 26 | **Soil Type** | Mixed black clayey and Brown loamy soil, | 213.63 | 3 | 5 | 55 | **Water Quality Index** | < 50 | 0.096 | 1 | |
| 27 | **Soil Type** | Red gravelly clay soil, | 204.47 | 3 | | 56 | **Water Quality Index** | 50.1 -100 | 29.34 | 2 | 5 |
| 28 | **Soil Type** | Red gravelly loam soil, | 1.03 | 5 | | 57 | **Water Quality Index** | 100.1 - 200 | 467.64 | 3 | |
| 29 | **Soil Type** | Red loamy soil | 102.53 | 4 | | 58 | **Water Quality Index** | 200.1 - 300 | 136.1 | 4 | |
| | | | | | | 59 | **Water Quality Index** | > 300 | 53.48 | 5 | |

196

# CHAPTER 7

# SUMMARY AND CONCLUSIONS

Groundwater stands out as the primary accessible water source when needed, distinguished from other available sources. Currently, it serves as the sole fresh water reservoir accessible for our daily requirements, encompassing drinking purposes. The depth of the water table fluctuates due to diverse factors such as topographical variations, lithology, rainfall patterns, soil composition, vegetation density, groundwater exploration activities, infiltration dynamics, and numerous other criteria. The decline in groundwater levels stems from multiple factors, including overexploitation, declining rainfall patterns, developmental projects, deforestation, and various other causes. The growing worry about groundwater relates to the influx of pollutants from diverse activities and the encroachment of seawater into coastal aquifers. Fulfilling human water needs necessitates sustainable groundwater resources accessible throughout all seasons and locations, achievable only through the adoption of scientific approaches such as artificial recharge techniques.

This research leverages the correlation among geology, geomorphology, groundwater development, groundwater quality, and groundwater recharge to comprehend the current scenario of groundwater availability. The study establishes connections between water quality, electrical resistivity methods, remote sensing (RS), and GIS-based techniques to identify zones with potential for groundwater and recharge. The primary objective of this study is to evaluate the geology, hydrogeochemistry, geophysical attributes, as well as surface and subsurface characteristics. This was conducted to pinpoint suitable locations for groundwater recharge in the Kanavi Halla sub-basin spanning Savadatti, Gokak, and Bailhongal taluks within the Belagavi district of Karnataka. An integrated approach was employed, involving field investigations such as the collection and analysis of water samples during both pre-monsoon and post-monsoon seasons to assess the quality of subsurface water resources. Additionally, the study utilized electrical resistivity surveys to interpret subsurface features and delineate zones with groundwater potential within the study area. Geological and geomorphological assessments of the sub-basin were conducted using topographic maps, remote sensing data, and field validations to determine the suitability of sites for groundwater recharge. The key conclusions drawn from this research endeavor, are summarized below:

- VES survey is one of the potential methods to describe the subsurface layers for groundwater investigation and to plan groundwater developmental strategies. The current study reveals the relation among the hydrogeological, geomorphic and geophysical parameters of groundwater.
- Forty vertical electrical soundings were carried out in the study area keeping in view accessibility and feasibility covering entire area. From the resistivity survey conducted in the KHSB shows that VES curves are of HAA-type, KQH-type, AKQH-type, HQH-type, K-type, AK-type, AAK-type, HA-type, A- type, KH-type, AA-type, H-type, HK-type, HAK-type, AAA-type, HKH-type and HKQQ-type allied with three, four, five and six layers and out of 40 VES, only 16 VES have been considered as good potential sites. 14 VES are found to be fair to good, whereas the remaining are showing poor potential. Good potential locations identified are VES No. 2,4,5, 6, 8,13,15, 17, 27, 28, 31, 32, 33, 37, 39 and 40.
- From the data, it is inferred that 50% of the study area is dominated by curves associated with A and K type, indicating hard rock terrain. It also revealed that some of these sites are very poor zones for groundwater availability.
- The collected ground data were analyzed and interpreted utilizing the IPI2Win Resistivity Sounding Interpretation Software (1990-2008). This software facilitated the generation of 2-D geo-electric sections from 1-D data to understand the geometry of the aquifer formed. In the present study the weathered, fractured and jointed formation may be interpreted as water bearing zone. The aim of the

investigation was to assess the aquifer within KHSB (Kanavi Halla sub-basin) and conduct a risk evaluation concerning potential contaminants' seepage. This assessment involved utilizing Dar-Zarrouk (D-Z) parameters such as longitudinal unit conductance (S), longitudinal resistivity (ρl), transverse unit resistance (T), transverse resistivity (ρt), Electrical anisotropy (λ), and root mean square resistivity (ρm). These parameters were analyzed to understand the aquifer's conditions and to delineate zones carrying freshwater. The findings indicate that the southeastern region of KHSB might be at risk of contamination, with approximately 22.5% of the area exhibiting a weak to poor capacity to protect against contaminants.

- The calculation of D-Z parameters for examination of aquifer protection studies is of great importance in order to overcome common issues like groundwater exploitation and groundwater protection from pollution.
- The present study highlights the combination of VES results, borehole logs, 2-D geo-electric sections and D-Z parameters in order to delineate the fresh groundwater potential zones in hard rock terrains.
- This work highlights the success of electrical resistivity technique in demarcating weathered, jointed and fractured zones which helps in identification of potential groundwater sites. Electrical resistivity survey technique proved useful in demarcating weathered, jointed and fractured rock successfully, thus helping in identifying the potential sites for high yielding boreholes.
- Groundwater quality analysis has been done for the 2 seasons. The Phase-I was conducted during pre-monsoon season of April 2018. Phase – II was carried out during the post monsoon season (December 2018). Forty-five and forty-one number of groundwater samples were collected during pre-monsoon and post-monsoon season respectively in a systematic manner by dividing the study area, into a number of grids of 4x4 $km^2$, to cover the entire stretch of the KHSB and analysed for physical and chemical parameters. From the water quality analysis, it is concluded that good number of water samples are exceeding the limits for

drinking water suitability whereas for agricultural suitability they are well within the limit.

- Several mathematical computations were performed to evaluate the suitability of groundwater for agricultural purposes within the study area. The assessed parameters included electrical conductivity (Ec), sodium percentage (Na%), sodium absorption ratio (SAR), permeability index (PI), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR), and Kelly's ratio. Various plots including Piper, USSL, Stiff, Durov, Schoeller, and Gibb's were employed in the evaluation of groundwater hydrogeochemistry.
- From the results the dominance of cations are in the order of Ca > Na > Mg > K > Fe and regarding anions it is $HCO_3$ > Cl > $SO_4$ > $NO_3$ > F based on their average value of each ion in KHSB. Gibbs plot demonstrates that the chemical composition of the water is significantly influenced by rock dominance. According to the Wilcox diagram, 23 samples fall within the doubtful to unsuitable category, with one sample deemed unsuitable. For agricultural suitability also it is essential to improve the quality since in some areas it is found as unsuitable.
- Multivariate statistical methods encompass a range of empirical techniques that offer insights into the physical and chemical attributes of groundwater systems across both spatial and temporal dimensions. Conventional methods of interpreting groundwater quality data using standard graphs and plots often fail to illustrate the simultaneous relationships among various ions or samples. Hence the correlation matrix is beneficial from which we have noted that the relation among variables showing the role of each chemical parameter in a number of influencing factors. From the Correlation coefficient and factor analysis using principal component analysis(PCA) for water quality data set for the KHSB revealed that, geological processes like weathering and dissolution of minerals, fertilizers and other organic matter from agricultural activities and where the source is non-agricultural, rainfall

and domestic wastewaters are the main reasons behind the variation of groundwater quality.

- The saturation indices obtained from hydro-chemical modeling for the mineral phases in the water indicate that the groundwater points are generally saturated concerning calcite, dolomite, and aragonite, except for a few points. However, they are undersaturated concerning halite, anhydrite, and gypsum.
- For obtaining an extensive overview of groundwater quality, the water quality index (WQI) stands out as one of the most effective tools available. Hence in the present study WQI is used to assess the drinking water suitability. The results obtained from water quality index will help to understand the overall quality of the water by spatial variable map. Based on the water quality index results and spatial distribution of the KHSB shows that 64.5 %, groundwater quality is poor to very poor condition and around 22 % falls under the good condition.
- This study helped in identifying the problems in water quality of the study area. Undesirable effects are observed and the information regarding the same was collected during the sampling by interacting with the people. From oral interaction with the people it is found that it is crucial to take steps towards betterment of water quality for drinking purposes.
- The outcome of the study showed the combination of traditional approach, multivariate statistics, PCA, WQI and GIS are useful in evaluating groundwater quality.
- The present study will be helpful to solve the problems of groundwater for both drinking and irrigation purposes in the KHSB. Further development of water resources in the areas like KHSB is essential.
- This investigation also focuses on the establishment of a thematic database, incorporating a total of 46 thematic layers employed within the study. These thematic layers encompass various elements such as lithology, geomorphology, DEM (Digital Elevation Model), drainages, slope, drainage density, land use/land

cover (lu/lc), soil types, lineaments, lineament density, longitudinal unit conductance, transverse unit resistance, transverse resistivity, longitudinal resistivity, electrical anisotropy, and groundwater recharge potential zones. The thematic database designed for assessing groundwater quality comprises parameters such as pH, electrical conductivity, total dissolved solids, total hardness, sodium, potassium, magnesium, calcium, nitrate, sulfate, iron, chloride, fluoride, bicarbonates, along with Water Quality Index (WQI) measurements for two distinct seasons. This comprehensive thematic database, coupled with WQI analysis, facilitates a deeper comprehension of the interrelations between these themes, aiding in the identification of suitable zones for groundwater exploration and recharge.

- For mapping suitable sites for groundwater recharge zones individual thematic maps are prepared from the satellite data, toposheet, field survey and available secondary data. In this study surface features like geology, geomorphology, soil type, lineament density, slope, drainage density and LU/LC are considered and subsurface features derived from water quality analysis such as WQI and VES survey data are used to extract, Electrical anisotropy(λ), Longitudinal unit conductance (S) and Transverse unit resistance (T).
- This study introduces crucial recommendations by suggesting the inclusion of additional layers essential for comprehensive analysis. These newly proposed layers consist of the Water Quality Index during the post-monsoon season, Longitudinal Unit Conductance (S), Transverse Unit Resistance (T), and Electrical Anisotropy (λ). These layers are obtained through Vertical Electrical Sounding (VES) using the Schlumberger configuration method, contributing significantly to the study's dataset and analytical framework.
- The study utilizes SRTM DEM data, featuring a spatial resolution of 30 meters. The data derived from the DEM, including the drainage network, slope are extracted and employed within this research. The delineation of the drainage

network includes streams up to the 7th order. The terrain exhibits "nearly level" slope categories throughout the entire study area, while notably " steep slopes" are observed towards the Western region of the study area which covers parts of Bailhongal and Savadatti taluks of Belagavi district.

- The higher the resolution, more the accuracy and things can be identified and can be differentiated easily. Hence to prepare lu/lc layer high resolution RESOURCESAT-I LISS-IV data has been used to enhance the accuracy of the results
- KHSB is covered by hard rock terrain. Recharge of groundwater in the present study area is very low to low. The results show 18.7% very low, 41.2% low, 29.6% moderate, and 10.5% high, area suitable for groundwater recharge. Total of 11 thematic layers are utilised for integration of site suitability for groundwater recharge (GWRZ) mapping. They are classified as very low to high where the category with "very low to low" covers larger area.
- Though several artificial recharge structures are existing in the present study area, based on the observation and topography, some more check dams, farm ponds, percolation tanks and recharging bore wells are recommended in this study area.
- GIS environment have made work much easier to create various thematic maps. Later those can be integrated to generate the most suitable groundwater recharge sites. For development of watershed in remote areas various factors are to be assessed which can be derived based on the RS data in which GIS play significant role to locate the suitable sites based on the final output by considering various factors. These kinds of scientific approaches will enhance the accuracy level for better way of water management. Study suggests suitable sites for groundwater recharge in Kanavi Halla sub basin.

## 7.1 LIMITATIONS

- For VES survey large open space is required and selection of site is difficult task in residential and densely populated areas.
- VES survey involves number of apparatus and accessories which is difficult to carry and involves laborious field procedure.
- This water quality investigation also explains the use of the multivariate statistical application in the hydrogeochemical analysis. The chances of failure of this kind of analysis may be due to the inadequate data, inappropriate frequency of observation of data and manual errors during the analysis of quality variables in the research laboratory. Because of this, it is necessary to give more importance to observed data and use the same in analysis systematically. For this purpose, the data has been adequately cross checked with the help of KMO and Bartlett's test, where results showed more than the minimum value.
- Irrespective of morphological features like, geology, soil type, this work can be practiced by considering little alterations, and modifications.
- In order to develop model efficiently for site suitability for groundwater recharge one has to consider factors like agricultural condition, environmental anxiety, wildlife safety and socio economic factors.

## 7.2 RECOMMENDATIONS

- Major part of KHSB is underlain by Deccan basalts, hence dug wells are the feasible structures in such cases.
- The work adequately highlights the practical use of geophysical techniques, combination of geo-electrical modelling, 2-D geo-electric sections, D-Z parameters, borehole log in order to delineate the fresh groundwater potential zones in hard rock terrains and in the groundwater resource assessment process and this technique is highly recommended for the area with similar geological setup

- The outcome of the study showed good compatibility of multivariate statistics, PCA, WQI and GIS in evaluating groundwater quality. By having an overall picture of the geographic areas of groundwater quality, one can organize and plan in a better way for the sustainability and management of groundwater resource in respect to both quality and quantity.
- KHSB is affected by water quality problems and there is need for improving the quality of the groundwater. The study discloses that the groundwater of the KHSB requires purification of water before drinking, and mainly there is a need to protect it from the pollution. Quality of the water can be improved in the study area from government agencies by planning groundwater recharge structures and improving the land by reducing the use of chemical fertilizers. There is a need to take up the problem of the study area by government since the overall quality of the water is very hard. Therefore, suitable remedial measures can be adopted.
- This work will help government agencies to improve the groundwater resource both in quality and quantity. The same work can be replicated to other semi-arid areas. In semi-arid, hard rock regions, development of ground water resources for domestic as well for irrigational use is of great importance.
- For artificial groundwater recharge sites there is a necessity to know the subsurface, which can be carried out by conducting VES without affecting the ground and by which we can understand the subsurface layers in detail. This case study recommends for integrated approach of VES survey, water quality study, RS and GIS along with field work for water resource management.
- For further improvement of groundwater resource in the study area, treating dug wells by artificial recharge, construction of nala bunds, check dams and gully plugs are recommended.

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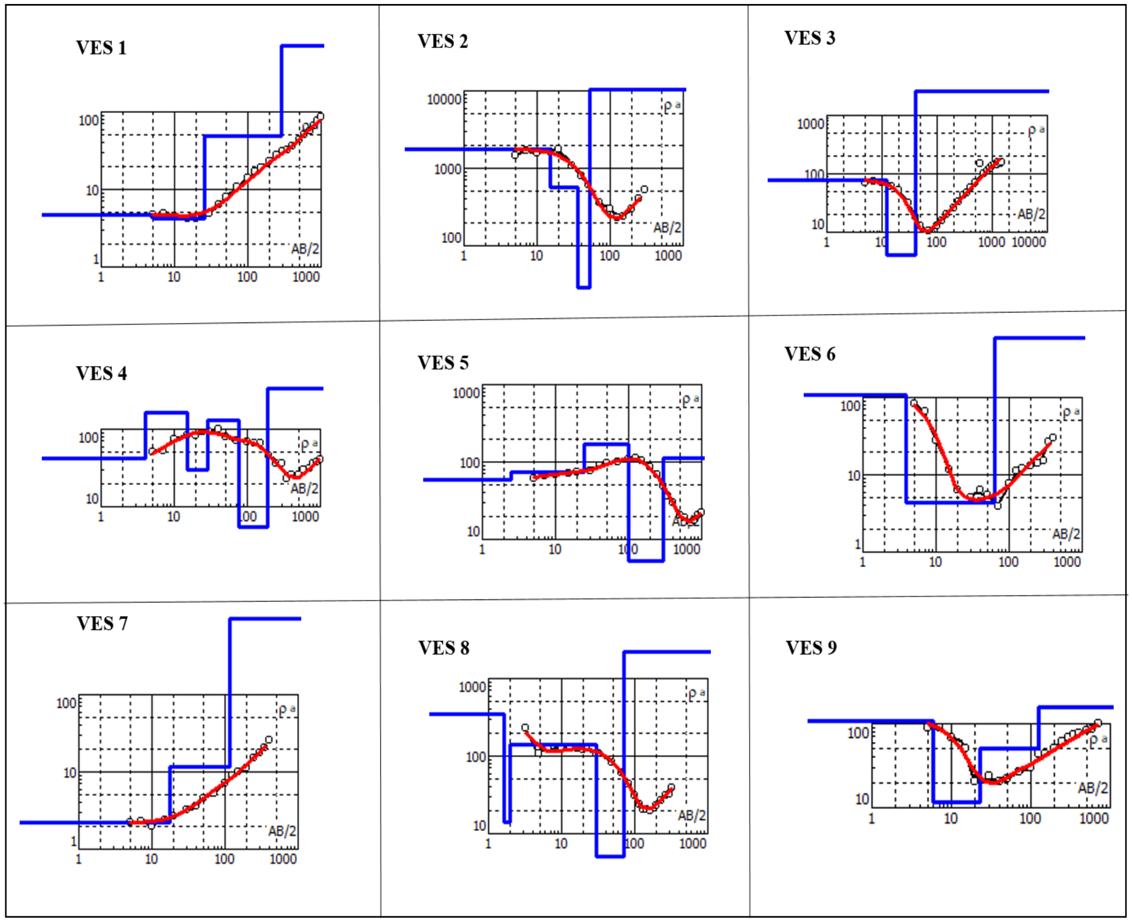
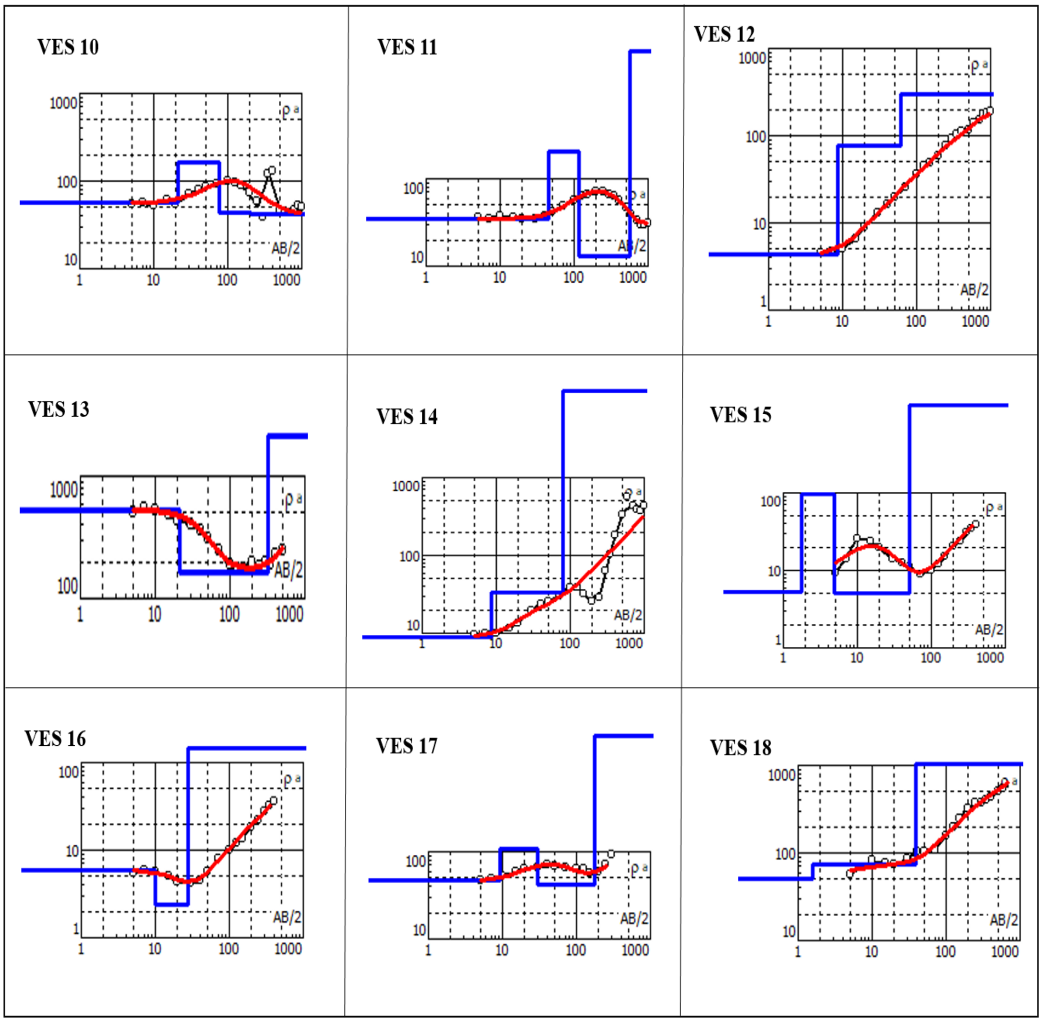
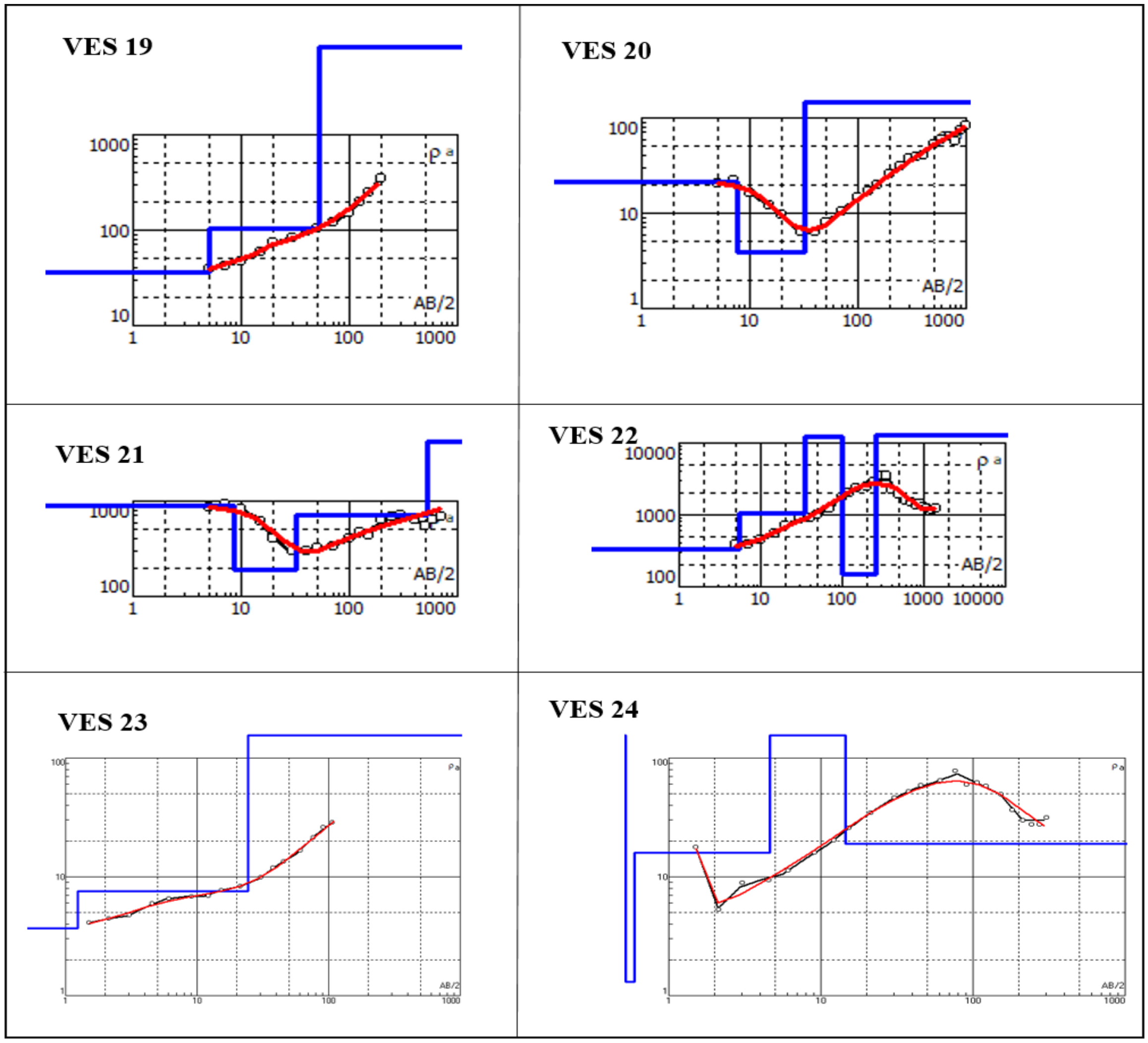
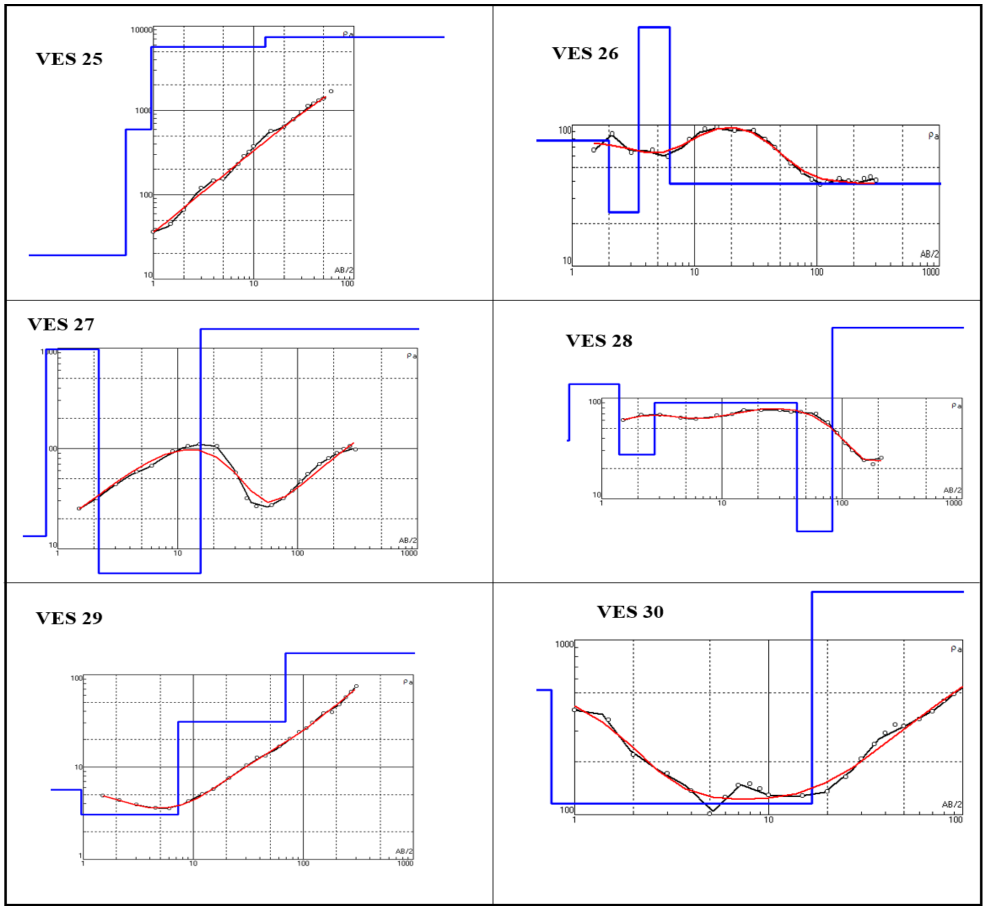
## APPENDIX – A

Electrical resistivity plots generated using IPI2WIN software for 40 VES locations




VES 10
VES 11
VES 12
VES 13
VES 14
VES 15
VES 16
VES 17
VES 18
ρ a
AB/2


VES 19
1000
100
10
1
10
100
1000
ρ a
AB/2
VES 20
100
10
1
1
10
100
1000
AB/2
VES 21
1000
100
1
10
100
1000
AB/2
VES 22
10000
1000
100
1
10
100
1000
10000
ρ a
AB/2
VES 23
VES 24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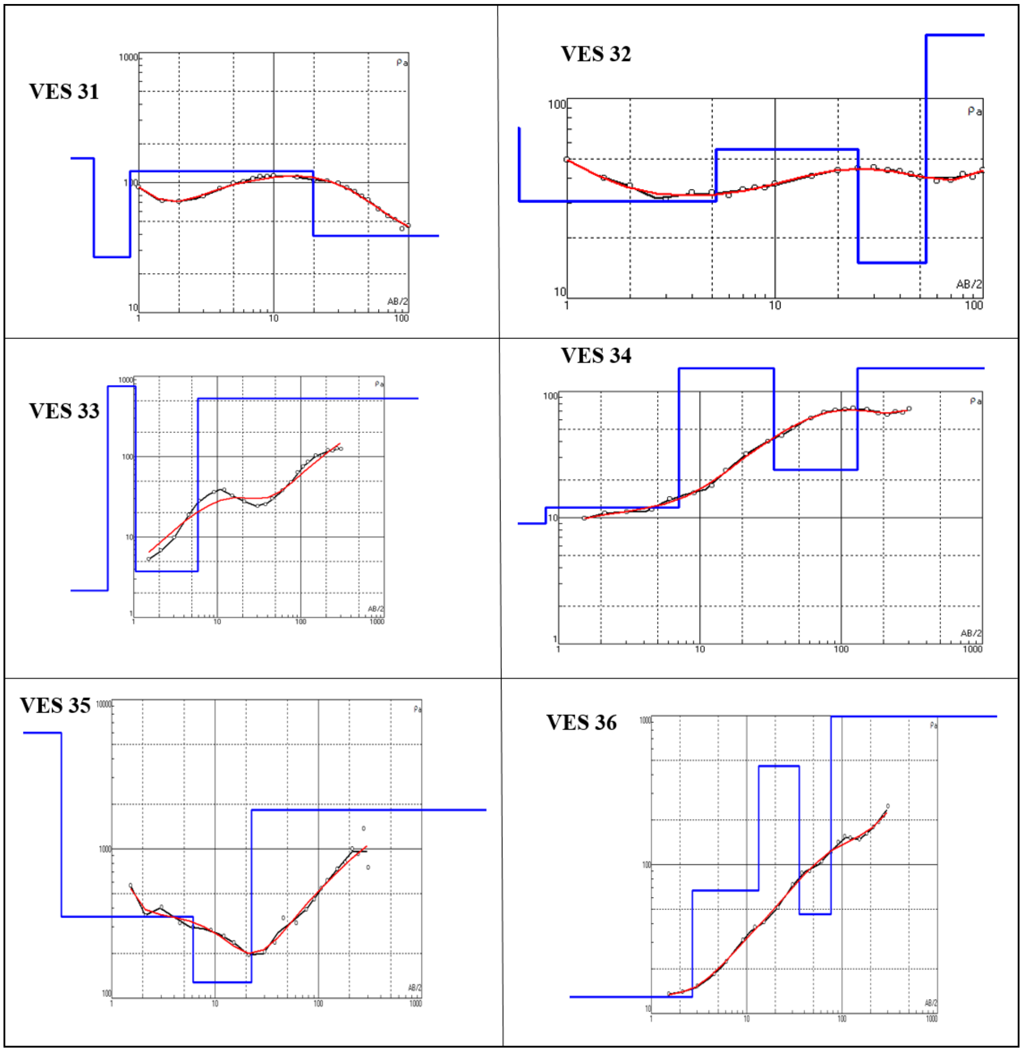
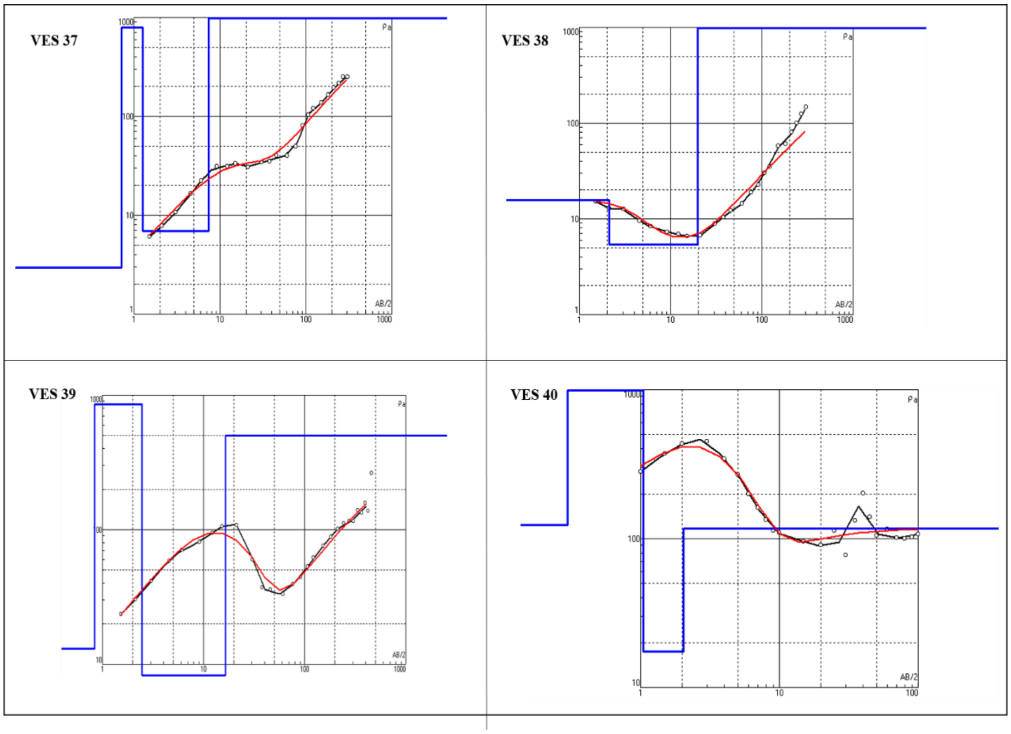
VES 26
VES 27
VES 28
VES 29
VES 30
AB/2


VES 31
VES 32
VES 33
VES 34
VES 35
VES 36


VES 37
VES 38
VES 39
VES 40

## APPENDIX-B

Appendix-B-1 Plate 1: Groundwater sample collection(PRM)

Appendix-B-2 Plate 2: Groundwater sample collection(POM)

Appendix-B-3 Plate 3: Groundwater sample collection (POM)

Appendix-B-4 Plate 4: Groundwater sample collection (POM) and water quality analysis in the NITK Laboratory

# APPENDIX – C

## LIST OF PUBLICATION

### JOURNAL PAPERS

1. **Venkanagouda B B Patil*,** Shannon M P, Thejashree G, Virupaksha H S, Vignesh Bhat and Lokesh K N (2020). "Multivariate statistics and water quality index (WQI) approach for geochemical assessment of groundwater quality—a case study of Kanavi Halla Sub-Basin, Belagavi, India." *Environmental geochemistry and health*, 42(9), 2667-2684. (Springer_SCI Indexed).

2. **Venkanagouda B B Patil**, Lokesh, K. N., Krishnamurthy, M. P., & Nadagoudar, H. V. (2020). "Delineation of Groundwater Potential Zones using Integrated Approach in Semi-Arid Hard Rock Terrain, Kanavi Halla Sub-Basin, Belagavi District, Karnataka." *Journal of the Geological Society of India*, 96(4), 410-419. (Springer_SCI Indexed)

### BOOK CHAPTERS

1 **Venkanagouda B B Patil** and Lokesh K N (2022). "Integrated approach for Groundwater Recharge Assessment - A Review" Groundwater and water Quality, Water science and Technology Library, Vol-119 pp.93-103 (Springer).

## INTERNATIONAL CONFERENCE PAPERS:

1. **Venkanagouda B B Patil** and Lokesh K N (2017) "Application of Electrical Resistivity Method for Ground Water Prospecting", International Conference on Global Civil Engineering Challenges in Sustainable Development and Climate Change (ICGCSC), pp 219-224.

2. **Venkanagouda B B Patil** and Lokesh K N (2018) "Multivariate statistics for groundwater quality assessment", Proceeding of the conference on NEXT FRONTIERS IN CIVIL ENGINEERING: Sustainable and Resilient Infrastructure. 30th Nov to 1st Dec 2018, pp.217-218, Paper ID: DJCE142.

3. **Venkanagouda B B Patil** and Lokesh K N (2018) "Groundwater development in hard rock terrains- A Review", Proceeding of the conference on NEXT FRONTIERS IN CIVIL ENGINEERING: Sustainable and Resilient Infrastructure, 30th Nov to 1st Dec 2018, pp.219-220, Paper ID: DJCE143.

4. **Venkanagouda B B Patil** and Lokesh K N (2018) "Integrated approach for Groundwater Recharge Assessment - A Review" pp.188, HYDRO International 2018, NIT Patna

5. **Venkanagouda B B Patil** and Lokesh K N (2019) "Integrated Study for Delineation of Groundwater Prospect Zones in Hard Rock Terrains - A Review" International Engineering Symposium (IES 2019) Kumamoto, Japan, March, 13-15, 2019.

## APPENDIX-D

## BIO-DATA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**ACADEMIC PROFILE**:

| Degree | Year of Completion | Institution | Board | Percentage/ CGPA |
|---|---|---|---|---|
| Ph.D. (Civil Engineering) | 2024 | National Institute of Technology Karnataka, Surathkal | Deemed University | 9.00 |
| M.Sc. (Applied Geology) | 2014 | Department of Applied Geology | Karnataka Universiy Dharwad | 78.31% |
| B.Sc (Physics, Maths, Geology) | 2012 | Karnataka Science College Dharwad | Karnataka Universiy Dharwad | 80.89% |
| PUC (PCMB) | 2009 | JSS Pre University College Vidyagiri Dharwad | Department of Pre-University Education, Karnataka | 69.83% |
| SSLC | 2007 | JSS Kannada Med School Vidyagiri Dharwad | Karnataka Secondary Education Examination Board | 84.64% |

## WORK EXPERIENCE

| Designation | Year of working | Department | Organization/Board |
|---|---|---|---|
| Assistant Professor | 2014-2016 | Civil Department | BGMIT Mudhol |
| Research Scholar(Full Time) | 2016-2019(Feb) | Civil Department | NITK Surathkal Mangalore |
| Research Scholar(Part Time) | 2019(Feb) to 2024 | Civil Department | NITK Surathkal Mangalore |
| Geologist | 2019(Feb) to present | Department of Mines and Geology, Belagavi | Goverment of Karnataka |

## PROFESSIONAL DETAILS

1. Life Member of “The Journal of the Geological Society of India.”
2. Life Member of “Mining Engineering Association of India Belgaum Chapter.”
3. Life member of “Geologist Association of Karnataka.”